Herpetofaunal Inventories of the National Parks of South Florida and the Caribbean: Volume IV. Biscayne National Park

By Kenneth G. Rice[1], J. Hardin Waddle[1], Marquette E. Crockett[2], Christopher D. Bugbee[2], Brian M. Jeffery[2], and H. Franklin Percival[3]

[1]U.S. Geological Survey, Florida Integrated Science Center

[2]University of Florida, Department of Wildlife Ecology and Conservation

[3]Florida Cooperative Fish and Wildlife Research Unit

Open-File Report 2006–XXXX

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Dirk Kempthorne, Secretary

U.S. Geological Survey
Mark Myers, Director

U.S. Geological Survey, Reston, Virginia 2006

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS=

Cite this report as: Rice, K.G., J.H. Waddle, M.E. Crockett, C.D. Bugbee, B.M. Jeffery, and H.F. Percival., 2006. Herpetofaunal Inventories of the National Parks of South Florida and the Caribbean: Volume IV. Biscayne National Park: U.S. Geological Survey, Open-File Report 2006-xxx, Fort Lauderdale, Florida.

Contents

Figures

Tables

Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre

Acronyms

AIC	Akaike's Information Criterion
BISC	Biscayne National Park
CI	Confidence interval
DOI	Department of Interior
GIS	Geographic information system
PAO	proportion of area occupied
PDA	personal digital assistant
SD	standard deviation
SE	standard error
SVL	snout-to-vent length
VES	visual encounter surveys
WGS	World Geodetic System

Herpetofaunal Inventories of the National Parks of South Florida and the Caribbean: Volume IV. Biscayne National Park

By Kenneth G. Rice, J. Hardin Waddle, Marquette E. Crockett, Chris Bugbee, Brian M. Jeffery, and H. Franklin Percival

Abstract

Amphibian declines and extinctions have been documented around the world, often in protected natural areas. Concern for this alarming trend has prompted the U.S. Geological Survey and the National Park Service to document all species of amphibians that occur within U.S. National Parks and to search for any signs that amphibians may be declining. This study, an inventory of amphibian species in Biscayne National Park, was conducted during 2002 and 2003. The goals of the project were to create a georeferenced inventory of amphibian species, use new analytical techniques to estimate proportion of sites occupied by each species, look for evidence of known stressors or problems that may lead to amphibian population decline (invasive species, disease, die-offs, and so forth), and to establish a baseline and methodology that could be used for future monitoring efforts.

Four sampling methods were used to accomplish these goals. Visual encounter surveys and anuran vocalization surveys were conducted at a total of 236 visits to 37 sites in all habitats throughout Biscayne National Park to estimate the proportion of sites or proportion of area occupied (PAO) by each amphibian species in each habitat. More than 100 individuals of 7 amphibian species were detected during standard sampling, and 24 individuals of 6 species of amphibians and 37 individuals of 12 species of reptiles were encountered during opportunistic

collections and nighttime road surveys used to augment the visual encounter methods for more rare or cryptic species opportunistically. The software PRESENCE was used to provide PAO estimates for each of the anuran species based on the visual encounter surveys and anuran vocalization data.

Amphibian species (six native and three non-native) were documented in Biscayne National Park during this project. The proportion of area occupied estimates obtained for the six most common amphibians will serve as a comparative baseline for future monitoring efforts. There were fourteen non-marine reptile species detected during this study. The proportion of area occupied for reptile species was not estimated because there were too few encounters during this study. The methods used in this study are adequate to produce reliable estimates of the proportion of sites occupied by most anuran species. Therefore, future sampling at regular intervals could be a cost-effective way of following amphibian occupancy trends.

This study identified some threats to amphibians in Biscayne National Park, especially introduced species including the Cuban treefrog (*Osteopilus septentrionalis*), the marine or cane toad (*Bufo marinus*), and the greenhouse frog (*Eleutherodactylus planirostris planirostris*) that were collectively detected nearly three times as often as native species.

Introduction

Declines in amphibian populations have been documented worldwide from many regions and ecosystems (Alford and Richards, 1999). No single cause for declines has been demonstrated, and it seems probable that several factors may interact to threaten populations (Carey and Bryant, 1995). A major factor in the loss of amphibian populations in the southeastern United States continues to be the loss of habitat (Dodd and Cade, 1998). In response to concerns about amphibian population declines, the Department of Interior (DOI) instituted long-term surveys of the status and trends of amphibians on DOI lands (U.S. Geological Survey Amphibian Research and Monitoring Initiative and National Park Service Inventory and Monitoring Network). Baseline inventories of amphibian species were conducted across the nation; this document describes an inventory of the amphibians of Biscayne National Park (BISC) conducted during 2002 and 2003.

The BISC (*http://www.nps.gov/bisc*) protects over 70,010 hectare (ha) of aquatic and terrestrial habitats. The BISC is located on the mangrove-lined southeast coast of Florida, south of Miami and east of Homestead in Miami-Dade County (fig. 1). The BISC is primarily an aquatic park protecting bay and reef habitats. The BISC does contain non-aquatic habitats consisting of several small islands and mainland that together constitute less than 5 percent of the total area of the park (fig. 2). These islands are part of the upper chain of the Florida Keys, and are located between Key Biscayne to the north and Key Largo to the south. Terrestrial habitats in BISC consist primarily of mixed mangrove forests and tropical hardwood hammocks.

Duellman and Schwartz (1958) produced the first complete species list of the herpetofauna of south Florida. Not every species listed as an inhabitant of south Florida is represented in BISC, presumably because of the limited habitat types. Most of the terrestrial habitat in BISC is naturally saline and lacking in permanent fresh water. Only a small portion of the total number of amphibian and reptile species that occur in south Florida are tolerant of, or adapted to, the saline environments in BISC. A systematic inventory of the herpetofauna of BISC has never been conducted. Therefore, the first objective of this study was to document all species of amphibians and, opportunistically, reptiles in BISC.

In addition to providing a sample of georeferenced locations of all amphibian species in BISC, this study enabled researchers to provide baseline information for future monitoring of amphibian status in BISC. The validation of the baseline information was accomplished with detection/non-detection data from repeated sampling at randomly chosen sites throughout BISC using the site occupancy estimation model developed by MacKenzie and others (2002). This method can serve as an index of abundance, and can be compared to future samples to determine trends in the status of amphibian populations. Similar sampling and analysis methods were employed in related projects in Everglades National Park and Big Cypress National Preserve (Rice and others 2004; Rice and others 2005). The methodologies developed in this study represent efforts to adaptively establish a protocol for future monitoring of amphibians in BISC.

Methods

Data for amphibians and reptiles were collected using several methods at sites throughout BISC in an attempt to identify species presence. Standard sampling at randomly chosen sites stratified by habitat included both visual encounter surveys (VES) and vocalization surveys. Other sampling included road cruises and visits to specific sites to search for other species. Opportunistic encounters with amphibians and reptiles were noted with details on the exact location of the capture and data on each individual animal.

Site Selection

Sampling sites were chosen randomly throughout BISC using a geographic information system (GIS), and all sampling was stratified by major habitat type. The BISC was divided into four natural habitats: hammock (habitat composed of primarily buttonwood forest), mangrove (habitats dominated by red mangrove, but including black and white mangrove as well), prairie (habitats dominated by graminoid plants), and mangrove scrub (habitats dominated by red mangrove scrub) (fig 3). Natural habitat designations were created by condensing the vegetation classification scheme proposed by Madden and others (1999) into our four broader habitat categories (table 1). Artificial habitat (disturbed areas significantly altered by humans) also was sampled. Opportunistic encounters were used to sample some structures such as buildings, roads, and canals.

We used ArcView® 3.2 was used with the Animal Movement Analysis extension (Hooge and Eichenlaub, 1997) to select points at random within each major natural habitat type. More random points were created than could be sampled, so points were selected from the list of available points for sampling based on availability of access. For example, if the next random point within a habitat was deemed inaccessible (no boat access, no road access, or extremely thick vegetation) after an attempt was made to visit it, the next random point was selected. Some portions of BISC were inaccessible by the means available to us (particularly much of the southern mainland area), but all designated habitats in BISC were sampled throughout the course of this study. Every habitat in BISC was sampled for 12 consecutive months during the period August 2002 through July 2003. The number of sampling occasions per site was variable. A total of 37 sampling sites were established with 16 sites sampled monthly and 21 sites sampled at least twice.

Repeated sampling at a subset of the more accessible sites was an efficient way to estimate habitat-level occupancy rates, while less frequent sampling at more remote locations provided better data on species distribution within BISC.

Visual Encounter Surveys

The primary method of sampling was a standard VES (Heyer and others, 1994) conducted for 30 minutes at the randomly chosen sites. All VES samples were begun at least 30 minutes after sunset because preliminary surveys in Everglades National Park indicated that amphibians were more active and more easily detected at night (Rice and others, 2004). Each VES was conducted by at least two experienced observers using powerful 6-volt lights with halogen bulbs.

The VES samples were all within a 20-meter (m) radius circle of the randomly chosen point, an area of 1256 square meters (m^2). While searching, judgment of the observers was used to stay within 20-m of the center point. Each circular plot as was searched as thoroughly as possible in the time allotted and all areas were covered at least in passing, however, judgment of the observers was used to determine which areas within the plot got the most emphasis. The goal was to find as many individual amphibians as possible; amphibian locations that could be searched included trees and other vegetation as well as bare ground and leaf litter.

An attempt was made to capture each individual amphibian and reptile that was observed during a VES. The animals were identified to species and sex, if possible, and the age/life stage (juvenile, adult, larva, and so forth) was recorded. The snout-to-vent length (SVL) of each animal captured was measured in millimeters (mm), and the substrate and/or perch height (estimated to the nearest 10 centimeters (cm)) on which each individual was first observed was noted.

In addition to the biological data collected during a VES, some key environmental data was collected in the field at the time of the survey. Air temperature and relative humidity was measured using a Spectrum Technologies, Inc. 3411WB digital thermohygrometer. Water temperature was measured and recorded if the plot was inundated. The weather was noted and classified into one of five categories: clear, partly cloudy, cloudy, rain, or fog. Wind speed was classified as none, light, moderate, or strong. The date and time of the sample and the observers present were also recorded. All data were recorded on personal digital assistants (PDAs) and later transferred to a Microsoft® Office Access database (Waddle and others 2003).

Anuran Vocalization Surveys

At each random point when a VES was conducted, all of the species of frogs and toads were noted that were heard vocalizing. The vocalization survey was a 10-minute period during the VES. All anurans that could be heard were included, even if it was possible or likely that they were calling from a location outside of the 20 m radius plot used for VES. The need to locate vocalizing individuals was eliminated by including all individuals heard, which facilitated comparison with similar surveys conducted elsewhere.

The abundance of vocalizing individuals was estimated as one of five categories: 1 individual, 2-5 individuals, 6-10 individuals, >10 individuals, or large chorus. The frequency of calling by each species was categorized as occasional, frequent, or continuous. These categories were discussed with newer observers in the field so that a consensus could be reached on which category to place the abundance and frequency of calls.

Additional Sampling

Additional sampling consisted of nighttime road surveys and opportunistic observations. Road surveys were used in addition to the standard sampling previously described above to attempt to fully document the amphibian and reptile fauna of BISC. Most of this sampling was performed to augment the species list. Data from this additional sampling were only included in the list of species detected and their locations. Because sites were not randomly chosen and sampling effort was not consistent, these data were not compatible with the proportion of sites occupied analysis technique used for the VES and vocalization surveys (see Data Analysis section).

Data Analysis

Detection probabilities for all amphibian and reptile species were assumed *a priori* to be less than one. Therefore, data were collected in a method compatible with the site occupancy model of MacKenzie and others (2002). This method estimated sampling occasion specific detection probabilities for each species using maximum likelihood statistical techniques. By estimating detection probabilities, it was possible to estimate the true site occupancy rate of each species by habitat, while taking into account the effects of environmental variables on the behavior of the animals. Detection rates were not assumed to be constant across species, habitats, time, or environment. However, if a species was present, a detection probability greater than 0 was assumed. Also, sites were assumed to be closed to changes in occupancy between subsequent samples. Therefore, only data from surveys that were conducted within six months of one another were considered.

This site occupancy model, when applied to randomly chosen sites in a defined area, was used to represent an estimate of the proportion of area occupied (PAO) by a species. This number was not an estimate of the abundance of individuals, but rather an estimate of the proportion of randomly chosen sites that were expected to be occupied by a given species. Because this model was based on repeated sampling and maximum likelihood techniques, it produced a robust estimate with a measure of precision that can be comparable to similar estimates obtained in other studies, including future monitoring of the same area.

All data were compiled in Microsoft® Office Access and then extracted as capture histories for analysis in the program PRESENCE (MacKenzie and others 2002). The detection data were too sparse to provide enough power to estimate habitat level occupancy rates, but, whether or not the site was on an island or the mainland was used as a site-specific covariable in the analysis. Variables that affect detection probability (p) were sampling occasion covariables: air temperature, relative humidity, presence of standing water. For each species, 14 models were considered that were combinations of those variables that were determined to be biologically meaningful *a prior* (table 2). As an example, the full model:

Psi(island); p(temp, humid, water)

estimated PAO (psi) as a function of the variable island (0=mainland, 1=island) and detection probability (p) as a function of temperature (degrees Celcius at time of survey), relative humidity (percent at time of survey), and presence of standing water (0=no water, 1=water present in plot). The model:

Psi (.); p(.)

estimated psi as a constant across all habitats and detection probability as a constant across all visits.

From MacKenzie (2002), the logistic model was required to relate covariates to occupancy and detection probabilities, such that:

$$\mathrm{Psi}_i = \frac{\exp(\beta_0 + \beta_1 X_i)}{1 + \exp(\beta_0 + \beta_1 X_i)}$$

$$p_{ij} = \frac{\exp(\beta_0 + \beta_1 X_i + \beta_2 Y_{ij})}{1 + \exp(\beta_0 + \beta_1 X_i + \beta_2 Y_{ij})}$$

Where X_i was a site specific covariate for site *i*, and Y_{ij} was a sampling occasion covariate for site *i* and time *j*. β_0 was the intercept term for the model, while β_1 and β_2 were the coefficients for the covariates. Therefore, in the example of the full model above:

$$\text{Psi(island)} = \frac{\exp(\beta_0 + \beta_1)}{1 + \exp(\beta_0 + \beta_1)}$$

$$\text{Psi(mainland)} = \frac{\exp(\beta_0)}{1 + \exp(\beta_0)}$$

The best model was the one with the lowest value for Akaike's information criterion (AIC), the most parsimonious model or the model with the best fit for the fewest parameters (Burnham and Anderson, 1998). This method of model selection allowed determination of the most important factors in sampling for individual species, and enabled selection of the best estimate of the site occupancy of each species. Generally, models with AIC values within 2 units of the best model were all considered as reasonable alternatives.

Overall site occupancy estimates were averaged across models weighted by AIC weights to produce the best estimate of the true PAO (Burnham and Anderson, 1998). Based upon AIC values (MacKenzie, 2002), the weight for the *j*th of the *m* models fitted to the data, w_j, was

$$w_j = \frac{\exp\left(-\Delta\text{AIC}_j\right)}{\sum_{k=1}^{m} \exp\left(-\Delta\text{AIC}_k\right)}$$

where ΔAIC_j was the difference in AIC between the minimum value and the value for model *j* (Burnham and Anderson, 1998). Model averaged estimates of the parameter (λ) and associated standard error (SE) were (Burnham and Anderson, 1998);

$$\bar{\lambda} = \sum_{j=1}^{m} w_j \hat{\lambda}_j$$

$$SE(\bar{\lambda}) = \sum_{j=1}^{m} w_j \sqrt{SE(\hat{\lambda}_j)^2 + (\hat{\lambda}_j - \bar{\lambda})^2}$$

Results

During this project, 8 amphibian and 8 reptile species were encountered during standardized sampling at the 37 sites that were visited at least twice (fig. 4). Between two and seven sites in each habitat were sampled monthly throughout the study (fig. 5). The highest number of study sites (19) was in mangrove habitat, and between 1 and 12 sites in each of the other habitats were visited (table 3). The total analysis included 236 site visits to the 37 sites.

An additional amphibian (one additional species was found just outside BISC boundary) and six reptiles were observed by opportunistic encounters and road cruises. Therefore, the total number of amphibian species documented in BISC during this study was 9, and the total number of documented reptile species in BISC was 14.

Specific capture information (table 4) and PAO model results (table 5) are presented in the following species descriptions. Appendix I presents β_i values for covariates present in the best model as determined by AIC. Although the best model minimized AIC, in some cases the SE's of the covariates are not useful for prediction. These results can be useful in determining the relationship between a covariate and the appropriate parameter. The best model is determined to be the most accurate given the set of models and the data. The most important use of the PAO results is as a baseline for future monitoring of these species.

During the study, researchers were prepared to collect specimens suspected of disease or other health problems and provide them to the U.S. Geological Survey National Wildlife Health Center for diagnosis. However, no individuals were suspect.

Acris gryllus

The Florida cricket frog (*Acris gryllus dorsalis*) is not common in BISC. Cricket frogs were detected in mangrove and mangrove scrub habitat within BISC during vocalization surveys, where they were heard on 6 of 236 sampling occasions at a total of 4 locations (fig. 6; table 6). Three of the locations were in mainland portions of BISC, but one site was on Elliott Key. No cricket frogs were directly observed during VES samples. Cricket frogs were detected by vocal surveys in March and again in May through August (table 7).

The naïve, or minimum, site occupancy for the species was 10.8 percent overall. The model-averaged PAO estimate for cricket frogs was 35.0 percent (SE = 0.2096) occupancy of all sites within BISC. The best model for site occupancy estimation included only island as a site covariate and no detection covariates, but several other models had weights (table 8). Island had the greatest variable contribution (0.55) to the model selection followed by the presence of ponded water (0.30), air temperature (0.23), and relative humidity (0.18) (table 9). Occupancy rates on islands were estimated as 8.6 percent (SE = 0.12) and 60.3 percent (SE = 0.39) at mainland sites.

Cricket frogs appear to be restricted to the mainland and Elliott Key within BISC. Cricket frogs are aquatic species usually found in association with permanent water (Conant and Collins, 1991), so it is unlikely that the species could survive on the other drier islands. Cricket frogs must also be limited in area on Elliott Key due to the lack of wet sites. BISC probably provides only marginal habitat for cricket frogs which are abundant throughout peninsular Florida.

Bufo marinus

The marine or cane toad (*Bufo marinus*) is a non-native species in Florida. It was first introduced into Miami-Dade County in the 1950s as a control for agricultural pests, but probably did not become established until subsequent releases of marine toads kept as pets (Meshaka and others, 2004). During the study, they were heard calling in every natural habitat within BISC and on 31 of 236 visits (table 6). Marine toads were observed on the mainland and on five of the six islands sampled (fig. 7). Vocalizations were heard from February through August and again in October and December (table 7). This species appears to be active throughout the year in south Florida.

The naïve, or minimum, site occupancy for marine toads was 37.8 percent across all sites, and the model-averaged PAO estimate was 77.9 percent (SE = 0.1499) occupancy of all sites within BISC. The best model for site occupancy estimation included no site covariate and only humidity as a detection covariate, but several other models had weights (table 10). Island had a relatively low variable contribution (0.18) to the model selection, and the presence of ponded water (0.25), air temperature (0.41), and relative humidity (0.50) were all higher (table 9). Occupancy rates on islands were estimated as 16.3 percent (SE = 0.82) and 93.3 percent (SE = 0.38) at mainland sites.

No marine toads were found within BISC during VES, but they were observed during opportunistic encounters. The best method for detecting this species appears to be listening for vocalizations. Humidity may be an important factor in determining when marine toads will vocalize. Because they were detected on so many different islands underscores the dispersal capabilities and the resiliency of this invasive species.

Bufo terrestris

The southern toad (*Bufo terrestris*), was detected on only one occasion in an opportunistic encounter in August 2003 just outside BISC boundary (fig. 8). This individual was found on a levee separating a canal habitat and a mangrove scrub habitat. There was no evidence of this species during the standard VES or vocal surveys. Detection rates for southern toads were low in Everglades National Park (Rice and others 2004), and it is likely that this species is difficult to detect outside of the breeding season.

Eleutherodactylus planirostris

The Greenhouse frog (*Eleutherodactylus planirostris planirostris*) was found in BISC (fig. 9). Greenhouse frogs were heard vocalizing on 26 of 236 visits to BISC (table 6). Vocalizations were concentrated between May and September. This period corresponds to the summer rainy season. During VES searches, 38 greenhouse frogs were found within BISC (hammock, mangrove, and mangrove scrub habitats). These frogs were found throughout the year (table 7), which indicates that they are active year round in south Florida. Based on the data collected during this study, either visual or vocal surveys are viable methods for monitoring greenhouse frogs. However, vocal surveys would be most effective during the rainy season. Snout-to-vent lengths of greenhouse frogs ranged from 11-23 mm with a mean of 19.33 mm (+/- 4.32 SD) (table 11).

The naïve, or minimum, site occupancy for greenhouse frogs was 37.84 percent overall, with the model-averaged PAO estimate of 54.4 percent (S. = 0.1077) occupancy of all sites within BISC. The best model for site occupancy estimation included island as a site covariate and only air temperature as a detection covariate, but several other models had weights (table 12). The air temperature variable had the greatest contribution (0.99) to the model selection, and island (0.69) and relative humidity (0.49) were both high also (table 9). The presence of standing water had the lowest variable contribution (0.21; table 9). Occupancy rates of greenhouse frogs at island sites were estimated as 87.6 percent (SE = 0.107) and 29.7 percent (SE = 0.152) at mainland sites.

Greenhouse frogs are well established in BISC. They appear to be most abundant and widespread on the islands of BISC and are possibly the most widespread of the three established exotic anurans in south Florida. Because greenhouse frogs are direct-developing frogs with terrestrial nests, it is not surprising that they are able to thrive where there is a lack of fresh water. This may also explain why standing water was relatively unimportant for model selection.

Gastrophryne carolinensis

Eastern narrowmouth toads (*Gastrophryne carolinensis*) were not encountered using VES or vocal surveys. However, there were three instances of narrowmouth toads in opportunistic encounters, one in August 2002 and two in March 2003. All of these observations occurred on Elliott Key (fig. 10), multiple individuals were seen in each case. In March 2003, a large chorusing aggregation was observed on two consecutive nights after a heavy rain. These frogs were encountered on a small road in mangrove habitat. Only one narrowmouth toad was captured during this study. This individual had a SVL of 30 mm, which is within the normal range of the species. No estimates of site occupancy are possible for narrowmouth toads in BISC due to the lack of encounters during standard sampling.

Eastern narrowmouth toads along with cricket frogs are the only native frogs found on any of the islands in BISC. It is not clear whether this is because of the by high dispersal ability in these species, or, if it is a function of the habitat requirements of these species. It is possible that narrowmouth toads are somewhat tolerant of salinity in water. They were commonly encountered in mangrove habitats in Everglades National Park (Rice and others, 2004). It is also possible that along with the introduced species and the cricket frogs, narrowmouth toads are able to reproduce in extremely ephemeral bodies of water. In either case, the freshwater puddles on Elliott Key represent an important resource for frogs.

Hyla cinerea

The green treefrog (*Hyla cinerea*) was the third most commonly observed amphibian species during our sampling in BISC; all observations of this species were on the mainland (fig. 11). This species was detected in mangrove and mangrove scrub habitat in BISC using either VES or vocalization methods. A total of 9 individual green treefrogs were captured during VES surveys, and at least 1 green treefrog was heard vocalizing during 19 of the 236 samples (table 6).

Green treefrogs were detected during March and again in May through September in the vocalization surveys and; green treefrogs were detected during May through August in VES surveys (table 7). This indicates that green treefrogs may be detectable in all seasons except winter in BISC. The period during which they were found vocalizing corresponds with the wetter part (May through September) of the annual rain cycle in south Florida. Morphometric data were collected from six green treefrogs captured during VES. The overall mean SVL of green treefrogs in BISC was 40.17 mm (+/- 5.58 SD) and a range from 30 to 47 mm (table 11).

The naïve, or minimum, site occupancy for green treefrogs was 18.92 percent overall, and the mean estimate of PAO was 43.67 percent (SE = 0.1519). The best model for site occupancy estimation included island as a site covariate and temperature as a detection covariate. Several other models had weight (table 13). Whether the site was on an island had the highest variable contribution (0.99), but the air temperature variable also had a large contribution (0.64). Relative humidity (0.22) and the presence of standing water (0.31) both contributed very little to the model selection (table 9).

Green treefrogs were the most abundant frog found in Everglades National Park (Rice and others, 2004). They were somewhat less commonly encountered in BISC, perhaps because they appear to be restricted to the mainland. Unlike cricket frogs and eastern narrowmouth toads, green treefrogs appear to be absent from Elliott Key. It is possible that this is due to the lack of freshwater breeding sites. The green treefrog is an able disperser and is highly arboreal as an adult. It seems most likely that inadequate breeding habitat would be the main obstacle for successful colonization of the larger islands of BISC.

Hyla squirella

The squirrel treefrog (*Hyla squirella*) was a relatively uncommon species in BISC (fig. 12). Squirrel treefrogs were not detected by VES or opportunistic encounters. Detection of squirrel treefrogs by vocalization occurred on 2 of 236 occasions (table 6) in July and August (table 7). These vocalizations were heard in mangrove and mangrove scrub habitats. Detection of squirrel treefrogs using VES and vocal surveys was successful in amphibian monitoring in Everglades National Park and Big Cypress National Preserve (Rice and others, 2004; Rice and others, 2005). Results suggest that squirrel treefrogs are rare in BISC.

The squirrel treefrog appears to be restricted to the mainland in BISC. There were too few encounters with this species to estimate site occupancy rates. It is likely that the habitats found along the strip of mainland in BISC are marginal for squirrel treefrogs. Future monitoring efforts may provide more information about the status of squirrel treefrogs in BISC.

Osteopilus septentrionalis

The Cuban treefrog (*Osteopilus septentrionalis*) is an exotic hylid species possibly present in BISC since the 1950s (Meshaka and others, 2000). This was the most commonly documented amphibian species during VES. Cuban treefrogs were detected by VES in mangrove and mangrove scrub habitats, and was also encountered opportunistically in disturbed areas (fig. 13), a distribution consistent with known habitat preferences for this species (Meshaka, 2001). Cuban treefrogs were also detected during vocalization surveys in mangrove and mangrove scrub habitats. Individual Cuban treefrogs (49) were captured during VES and at least a vocalization was heard during 21 of the 236 sampling occasions (table 6). The overall mean SVL of Cuban treefrogs captured during this study was 57.45 mm (+/- 15.88 SD) (table 11). Cuban treefrogs were detected by VES every month of our sampling year except July and December, indicating that they are active throughout the year and probably detectable using visual techniques. Cuban treefrogs were detected by vocal survey during February and during April through October (table 7).

The naïve, or minimum, site occupancy for the species was 32.43percent overall, and the mean estimate of PAO was 48.61 percent (SE = 0.1157). The best model for site occupancy estimation had no site covariate and only relative humidity as a sampling covariate, but several other models had weight (table 14). Relative humidity had the highest variable contribution to model selection (0.46) and air temperature (0.38), island (0.31), and standing water (0.21) all had moderate contribution values (table 9). Occupancy rates of Cuban treefrogs at island sites were estimated as 34.7 percent (SE = 0.2156) and 56.9 percent (SE = 0.1930) at mainland sites.

Cuban treefrogs are firmly established in BISC and were found on all of the major islands (Elliott Key, Boca Chita, Sands Key) as well as the mainland. They were also the most commonly encountered frog species during surveys. This highly invasive species (Meshaka, 2001) is a potential threat to other small vertebrates in BISC.

Rana grylio

The pig frog (*Rana grylio*) can be found in the canals that form the boundary of BISC (fig. 14). This species was detected in canals during vocalization surveys, although the frogs were never actually in the plots. Pig frogs were heard in the vicinity of mangrove and mangrove scrub on 12 of 236 sampling occasions (table 6). These occurred in March through August (table 7). No pig frogs were observed during VES, although they were spotted during opportunistic encounters several occasions in canals. During the study, no pig frogs were captured for measurement.

The pig frog is a highly aquatic species that rarely leaves permanent water (Ashton and Ashton, 1988). Therefore, it is unlikely that this species will expand its distribution in BISC. It may be restricted to that canals that form the boundary along the western edge of BISC. No site occupancy estimates were produced for this species because it was never detected outside of the canals along BISC boundary.

Rana sphenocephala

The southern leopard frog (*Rana sphenocephala*) was encountered using VES techniques in mangrove habitat on 4 of 236 occasions throughout this study; three of these encounters occurred on one sampling occasion. Leopard frogs were heard in mangrove and mangrove scrub habitats during 5 of 236 vocalization surveys (table 6). All detections by vocalization occurred in January and February 2003 (table 7). Leopard frogs were observed during VES in August and June 2003 (table 7), and were observed during opportunistic encounters several times opportunistically in mangrove and disturbed habitats, especially the levees near canals (fig. 15). Only one leopard frog was measured (table 11).

The naïve or minimum site occupancy for the species was 13.51 percent overall, and the estimate of PAO was 48.57 percent (SE = 0.0026). The best model for site occupancy estimation included island as a site covariate and air temperature as a sampling covariate (table 15).

These results suggest that leopard frogs are relatively uncommon in BISC, and they appear to be absent from the islands. Visual methods seem to be the most reliable method of detecting leopard frogs, especially in summer months. Vocal surveys are better in the winter, when leopard frogs tend to breed (Ashton and Ashton, 1988). A selective search of canal habitat may yield the best results in documenting this species.

Reptiles

While the primary focus of this study was to sample amphibian species within BISC, many of the methods used were also appropriate for sampling reptiles. Therefore, data on reptile species encountered during this study were collected and summarized. The BISC website (Appendix II) listed 25 species of non-marine reptiles present in BISC. During this study, we encountered 14 of those species were encountered through various methods (table 16). Maps of the locations of occurrences by species are shown alphabetically within classes: Crocodilians (figs. 16 and 17); Lizards (figs. 18-23): and snakes (figs. 24-29).

During this study four reptile species were found that are not native to south Florida. The brown anole, *Anolis sagrei*, was the most abundant exotic reptile found in BISC, with 246 individuals being observed during VES alone. Brown anoles were primarily found near disturbed areas within BISC (fig. 19). Another exotic, the tropical house gecko, *Hemidactlyus mabouia,* was also found near disturbed areas (fig. 22). During VES, 26 individual house geckos were found with the majority of these being on buildings. The Indo-Pacific gecko, *Hemidactylus garnotti*, was found on two occasions during VES in hammock and prairie habitats (fig. 21). A single deceased Brahminy blindsnake, *Ramphotyphlops braminus*, was opportunistically encountered on one occasion in a disturbed area (fig. 29).

In addition to exotics, two reptile species of concern were encountered during this study. The American alligator, (*Alligator mississippiensis*), is listed as a "species of special concern" by the State of Florida, and as "threatened due to similarity of appearance" by the U.S. Fish and Wildlife Service (Federal Register 40:44149). Alligators are widespread throughout BISC and three individuals were found during opportunistic encounters (fig. 16). The American crocodile, (*Crocodylus acutus*), is listed as “endangered” by both the State of Florida and the U.S. Fish and Wildlife Service (Federal Register 40:44149). Crocodiles were encountered on one occasion during VES surveys (fig. 17).

Conclusions

This study represents the first thorough inventory of amphibian species in Biscayne National Park, and provides a clear idea of the distribution of each species geographically throughout the park BISC. The greatest value of this work is as a baseline for comparison in future monitoring efforts.

This inventory of BISC was designed to serve as a baseline for future monitoring efforts to ensure that no amphibian species declines will be recognized as scientifically important. The data collected during these surveys documents the distribution of amphibian species among habitats and across BISC in 2002-2003. The PAO technique employed in this study provides a robust estimate of the true number of sites occupied given that not all species are perfectly detectable. Future surveys conducted using similar methods will be directly comparable because the issue of changing detectability of individuals across time and observers is explicitly addressed in the analysis (MacKenzie and others, 2002).

Succeeding surveys should be conducted on a 5-10 year basis. The surveys should use both VES and vocalization techniques in the field, as neither method alone was sufficient for all species. Sites should be chosen randomly throughout BISC. Sampling could be conducted just during the warmer, wetter months for maximum efficiency as very little information was obtained by including the data collected during the winter months. Because PAO could not be estimated for some of the rarer species, sampling effort may need to be increased if monitoring of all species is desired. Estimates of proportion of sites occupied with confidence intervals from future monitoring can be directly compared to the estimates from this study. For example, an increase in PAO of 0.2 would be interpreted as a 20 percent increase in the number of sites occupied. Although these methods do not allow an estimate of the absolute abundance of amphibians, they do provide a convenient surrogate: the abundance of sites occupied by each species. This number is more easily obtained and comparable across time and among different sampling techniques.

Another goal of this project was to determine if there was evidence of threats to any of the native species of amphibians found in BISC. No species of amphibian's present in BISC during this study appeared to be threatened by disease, other health-related problems, or show extremely low PAO when compared to populations in nearby Everglades National Park (Rice and others, 2004). However, PAO was estimated for only 3 native species due to low captures, very similar to Everglades National Park in mangrove habitat. This is encouraging given the apparent declines of many amphibian species in protected areas worldwide (Alford and Richards, 1999). However, as no previous complete surveys exist, it is uncertain whether other species were formerly present, or, if the species currently present were formerly more abundant. Future surveys should provide better data of the long-term trends of distribution and abundance of the native amphibians.

The main threat identified to native amphibian species in BISC is the presence of invasive exotic species. Of the 9 anuran species documented in BISC, 3 have been introduced. These include the Cuban treefrog (*Osteopilus septentrionalis*), the marine toad, cane toad or giant toad (*Bufo marinus*), and the greenhouse frog (*Eleutherodactylus planirostris*). All three of these introduced species were discovered on the islands of BISC and represent 60 percent of the amphibian species on these islands. Further, the estimated mean PAO of the invasive species (range 48.61-77.90) were higher than any of the native species (range 35.0-48.57) and were encountered almost three times as often in our study. The two native anurans found on the islands, the narrowmouth toad (*Gastrophryne carolinensis*) and the cricket frog (*Acris gryllus*), were only observed on Elliott Key. All three of the introduced species were relatively common and were found on numerous occasions on many islands. The Cuban treefrog and the giant toad were found in a variety of habitats. The Cuban treefrog has reached very high densities at some sites in Everglades National Park, especially near Flamingo and in Long Pine Key. The diet of the Cuban tree frog includes a variety of vertebrate prey (Meshaka, 2001, Maskell and others, 2003). The impact to the native treefrog assemblage is under investigation, but it appears that the combination of direct and indirect competition and predation allows Cuban treefrogs to increase to the detriment of native species (Kenneth G. Rice, U.S. Geological Survey, unpublished data). The marine toad is another introduced species that may have a negative impact on native fauna of BISC. This species is also an aggressive predator, and although it is relatively rare in the natural areas of south Florida now, it may be increasing in abundance and expanding its range (Rice and others, 2004, Rice and other, 2005).

Acknowledgements

The authors would like to thank the technicians that assisted with the field work in this project: University of Florida staff Amber Dove, Andy Maskell, and Phil George. The staff at Biscayne National Park provided valuable logistical help. Matt Patterson, National Park Service Inventory and Monitoring Program is appreciated for providing funding and for helping to initiate this project. Biscayne National Park loaned a vehicle and allowed the use of their boat launch. Administrative services were managed by the support staff at the University of Florida, Ft. Lauderdale Research and Education Center, especially Sarah Kern, Veronica Woodward, Jocie Graham, Alicia Weinstein, and Valerie Chartier. Valuable comments were provided for this manuscript by Amanda Rice (University of Florida) and Mike Deacon (U.S. Geological Survey).

References

Alford, R. A., and Richards, S. J., 1999, Global amphibian declines: a problem in applied ecology. Annual Review of Ecology and Systematics 30:133-165.

Ashton, R. E., and Ashton, P. S., 1988, Handbook of reptiles and amphibians of Florida part three: The amphibians. Windward Publishing, Miami, FL, USA.

Burnham, K. P., and Anderson D. R., 1998, Model selection and multi-model inference: a practical information-theoretic approach. Springer-Verlag, New York, NY, USA.

Carey, C., and Bryant C. J., 1995, Possible interrelations among environmental toxicants, amphibian development, and decline of amphibian populations. Environmental Health Perspectives 103:13-17.

Conant, R., and Collins J. T., 1991, A field guide to reptiles and amphibians: eastern and central North America, 3rd edition. Houghton Mifflin Company.

Dodd Jr., C. K., and Cade B. S., 1998, Movement patterns and the conservation of amphibians breeding in small, temporary wetlands. Conservation Biology 12:331-339.

Duellman, W. E., and Schwartz A., 1958, Amphibians and reptiles of southern Florida. Bulletin of the Florida State Museum 3:179-324.

Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L. C., and Foster, M. S., 1994, Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution Press, Washington, DC.

Hooge, P. N., and Eichenlaub B., 1997, Animal movement extension to ArcView. *in*. Alaska Science Center - Biological Science Office, U.S Geological Survey, Anchorage, AK, USA.

MacKenzie, D.I. 2002. Modeling handout. U.S.Geological Survey Patuxent Wildlife Research Center, 6 pp.

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, J. A., and Langtimm, C. A., 2002, Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2256.

Madden, M., Jones, D., and Vilchek, L., 1999, Photointerpretation key for the Everglades vegetation classification system. Photogrammetric Engineering & Remote Sensing 65:171-177.

Maskell, A. J., Waddle, J. H., and Rice, K. G., 2003, Osteopilus septentrionalis: Diet. Herpetological Review 34:137.

Meshaka, W. E., 2001, The Cuban treefrog in Florida. University of Florida Press, Gainesville, FL.

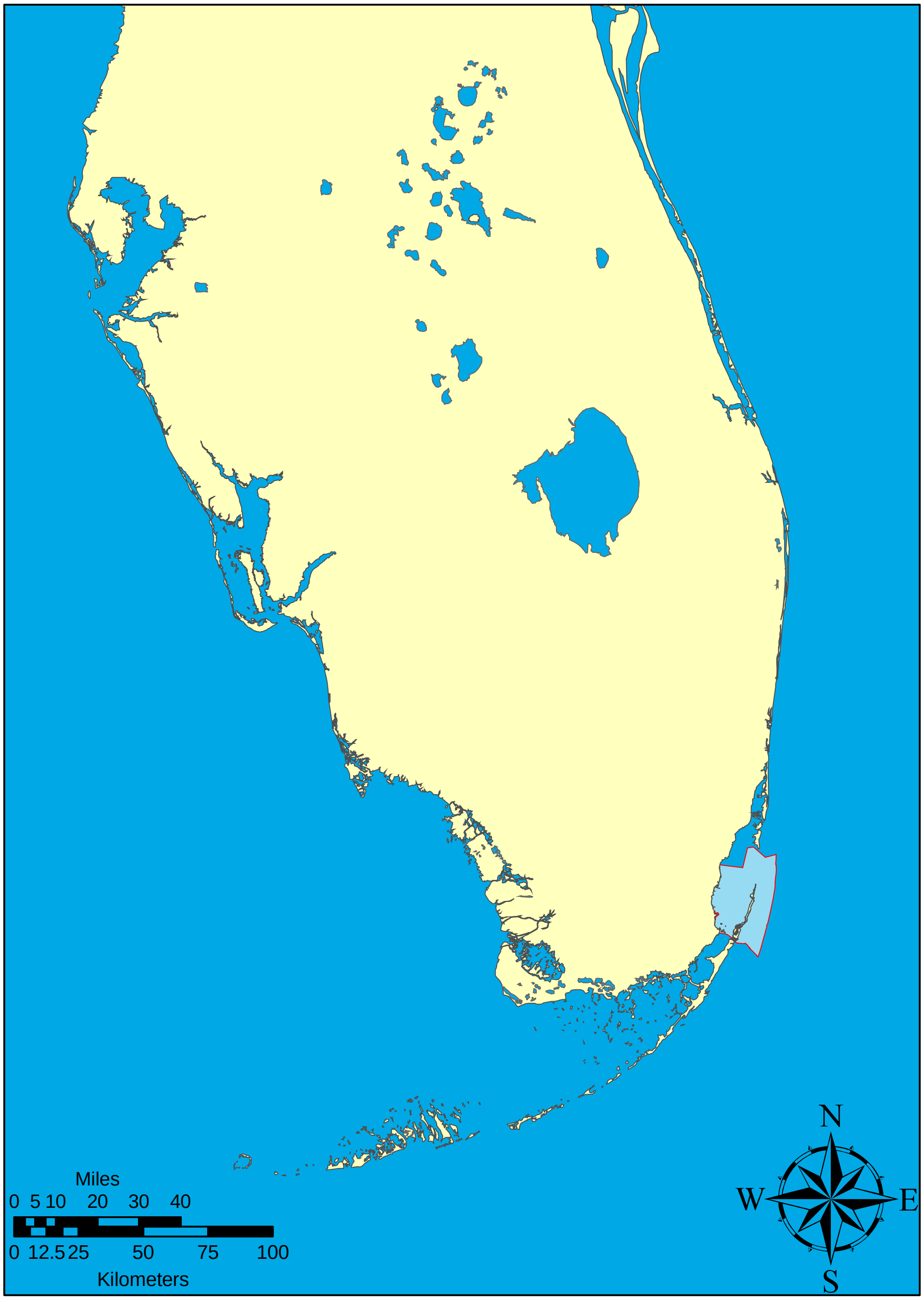
Meshaka, W. E., Loftus, W. F., and Steiner, T., 2000, The herpetofauna of Everglades National Park. Florida Scientist 63:84-103.

Meshaka W.E., Butterfield, B.P, and Hauge, J.B., 2004, The Exotic Amphibians and Reptiles of Florida. Krieger Publishing Co., Malabar, FL 155 pp.

Rice, K.G., Waddle, J.H., Crockett, M.E., Jeffrey, B.M., and Percival, H.F., 2004, Herpetofaunal Inventories of the National Parks of South Florida and the Caribbean: Volume 1. Everglades National Park: U.S. Geological Survey Open-File Report 2004-1065.

Rice, K.G., Waddle, J.H., Crockett, M.E., Jeffrey, B.M., and Percival, H.F., 2005, Herpetofaunal Inventories of the National Parks of South Florida and the Caribbean: Volume III. Big Cypress National Preserve: U.S. Geological Survey Open-File Report 2005-1300.

Waddle, J. H., Rice, K. G., and Percival, H. F., 2003, Using personal digital assistants to collect wildlife field data. Wildlife Society Bulletin 31:306-308.



Explanation

Biscayne National Park

Figure 1. *S*outhern Florida showing location of Biscayne National Park.

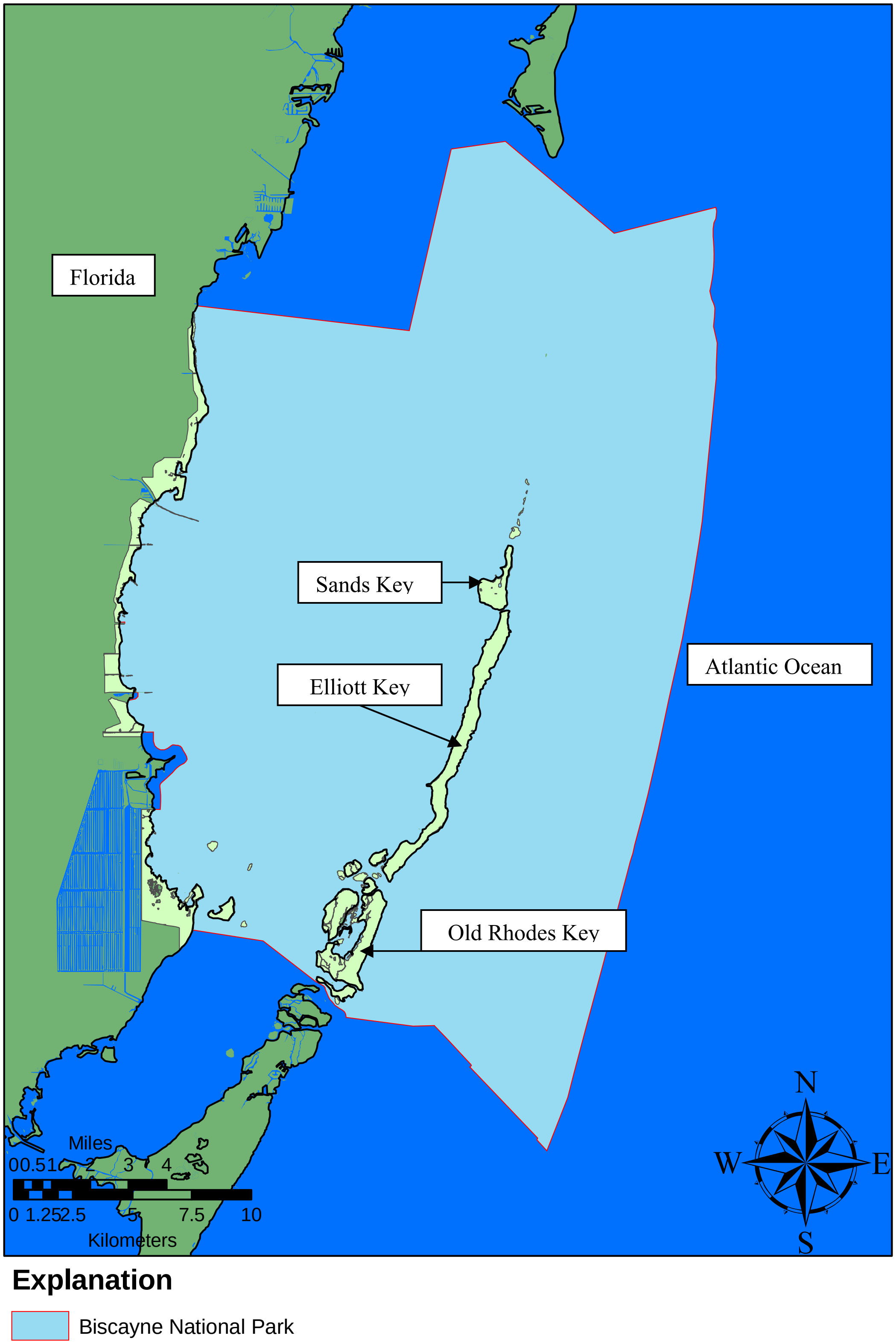


Figure 2. Enlarged location of Biscayne National Park in southern Florida.

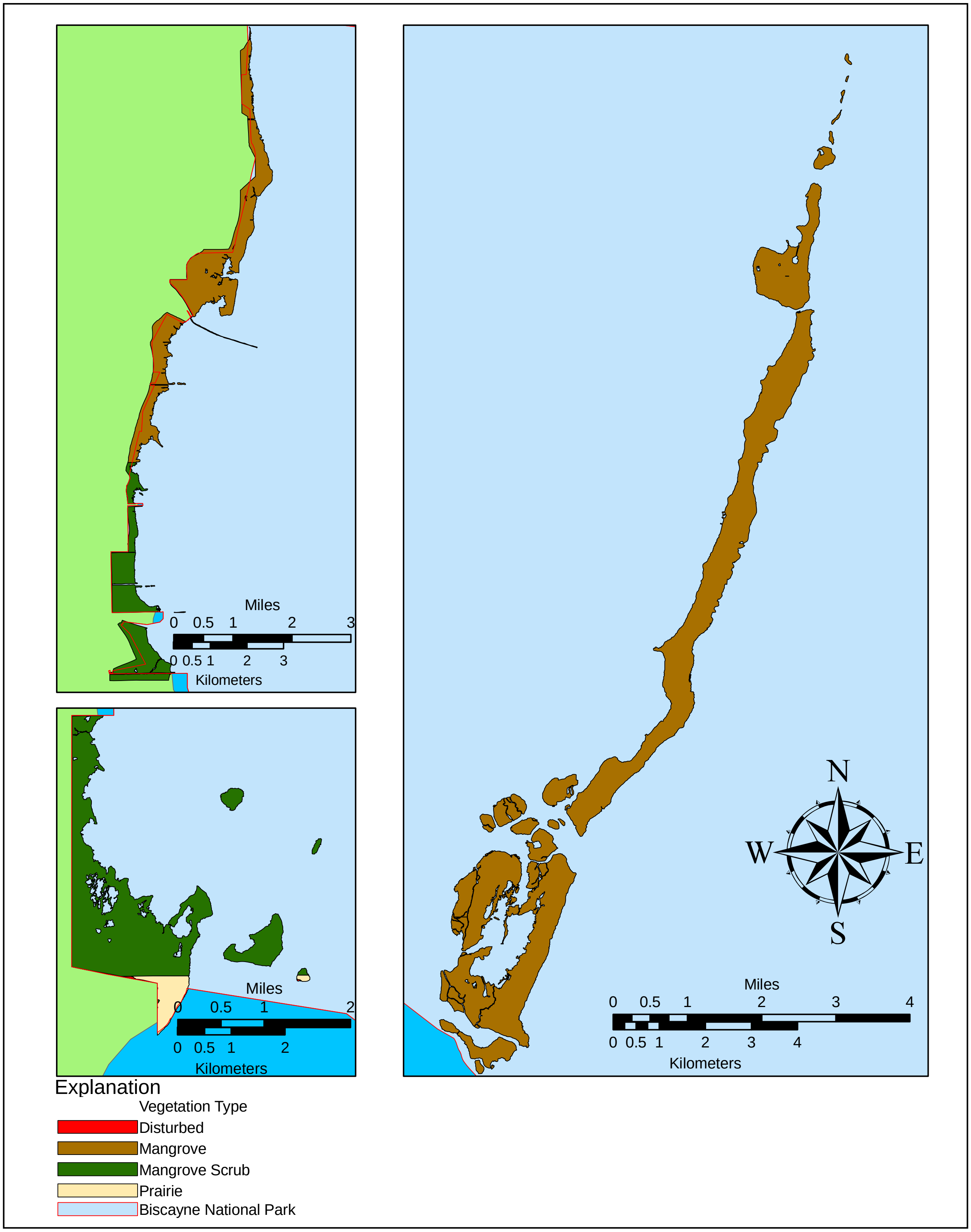


Figure 3. Vegetation classifications of Biscayne National Park. Hammock vegetation was also sampled in island habitat of right panel, however, patch size is too small to appear in this figure. Please refer to figure 2 for enlarged view and other detail.

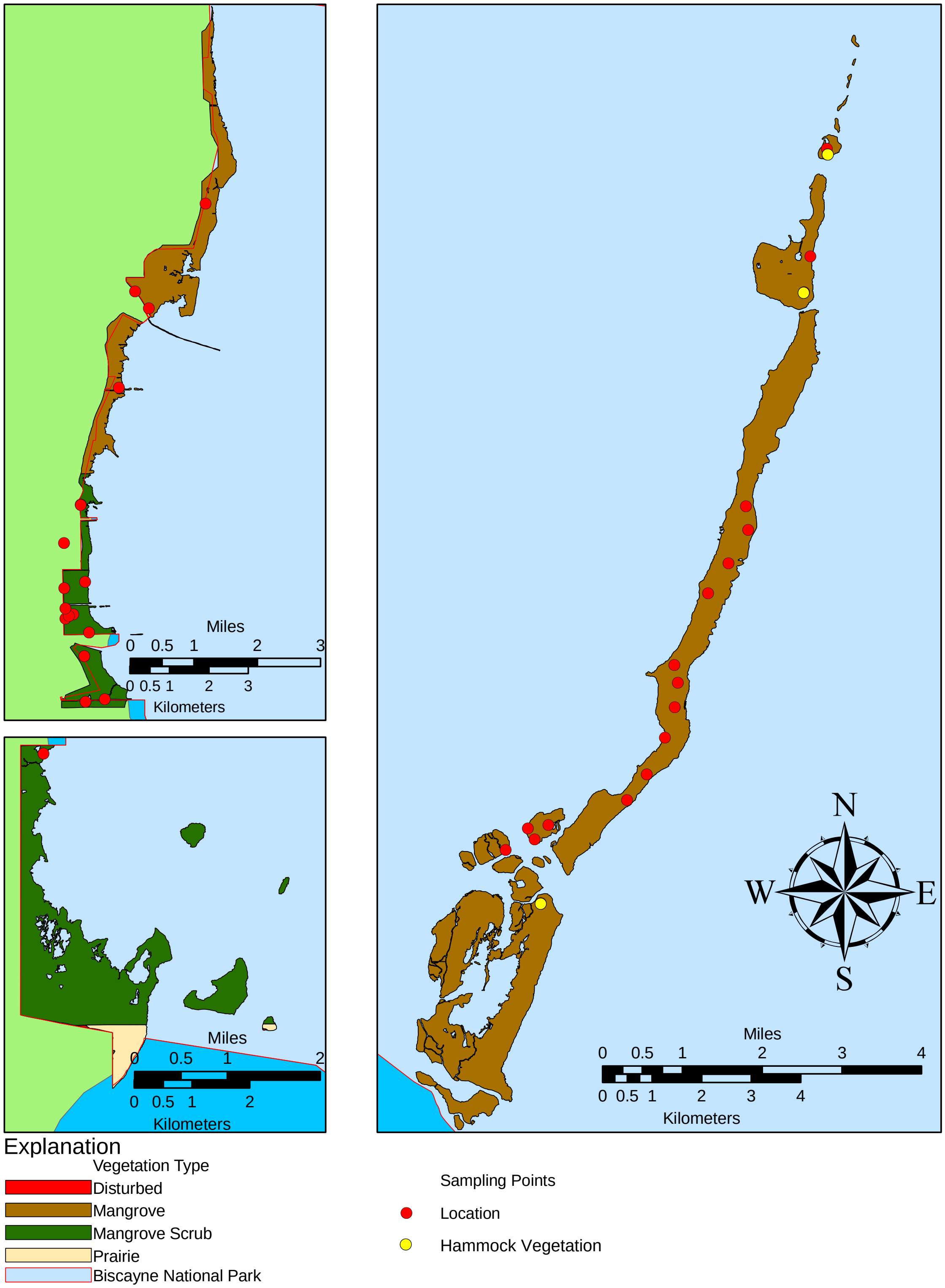


Figure 4. Sampling locations (37) at which visual encounter surveys and vocalization surveys were conducted at Biscayne National Park.

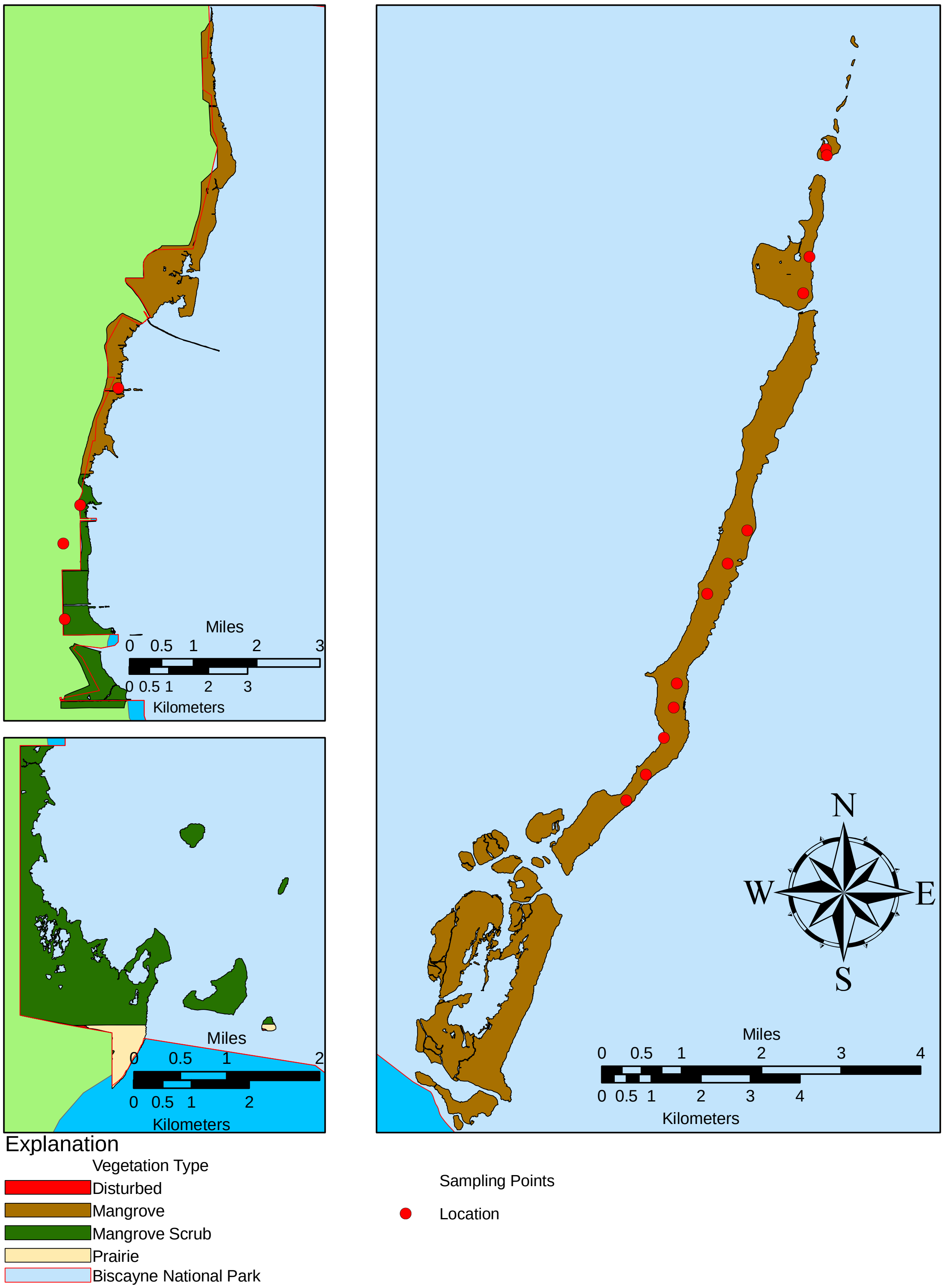


Figure 5. Locations (16) at which visual encounter surveys and vocalization surveys were conducted on a monthly basis at Biscayne National Park.

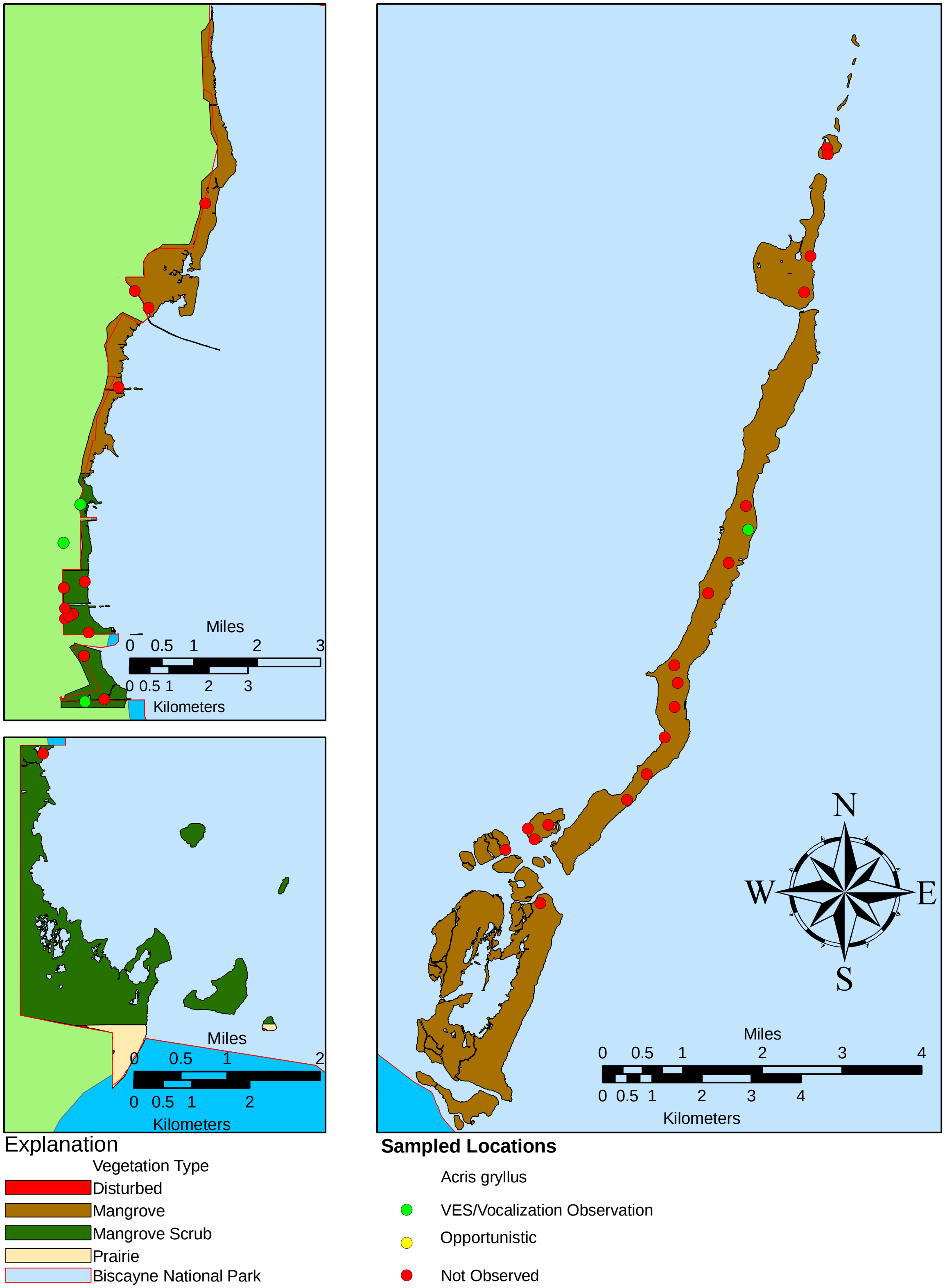


Figure 6. Locations at which *Acris gryllus* were observed at Biscayne National Park.

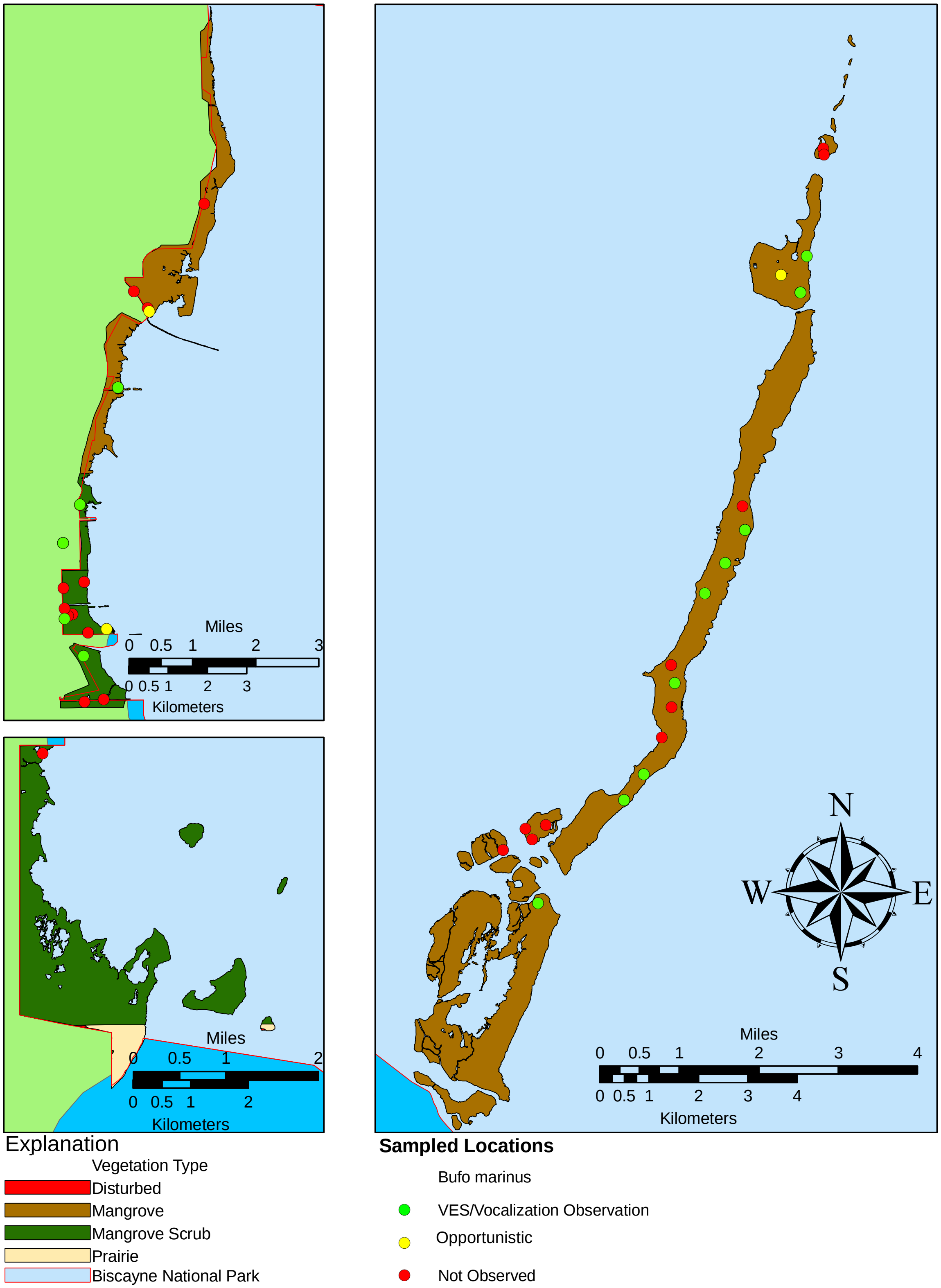


Figure 7. Locations at which *Bufo marinus* were observed at Biscayne National Park.

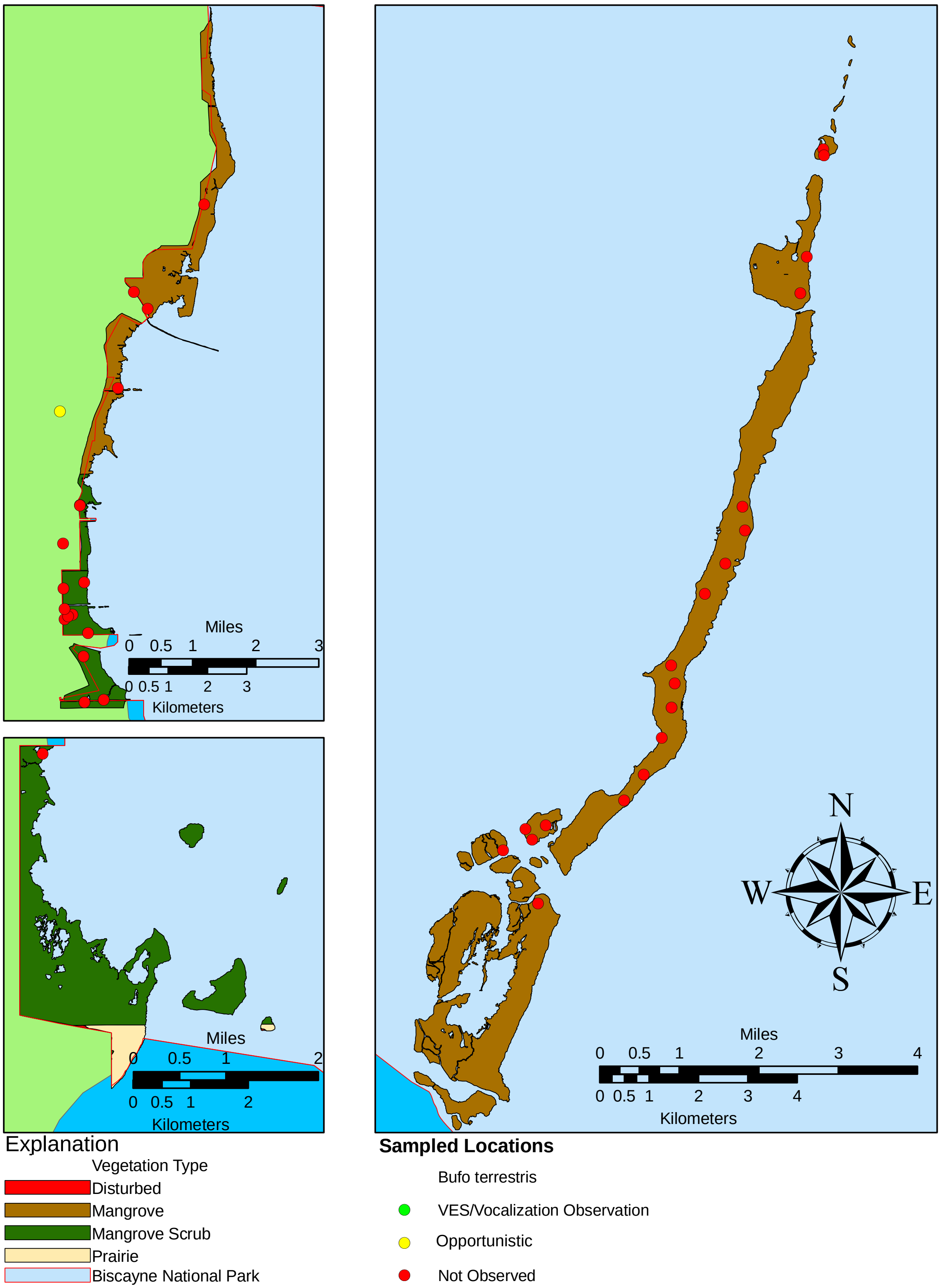


Figure 8. Locations at which *Bufo terrestris* were observed at Biscayne National Park.

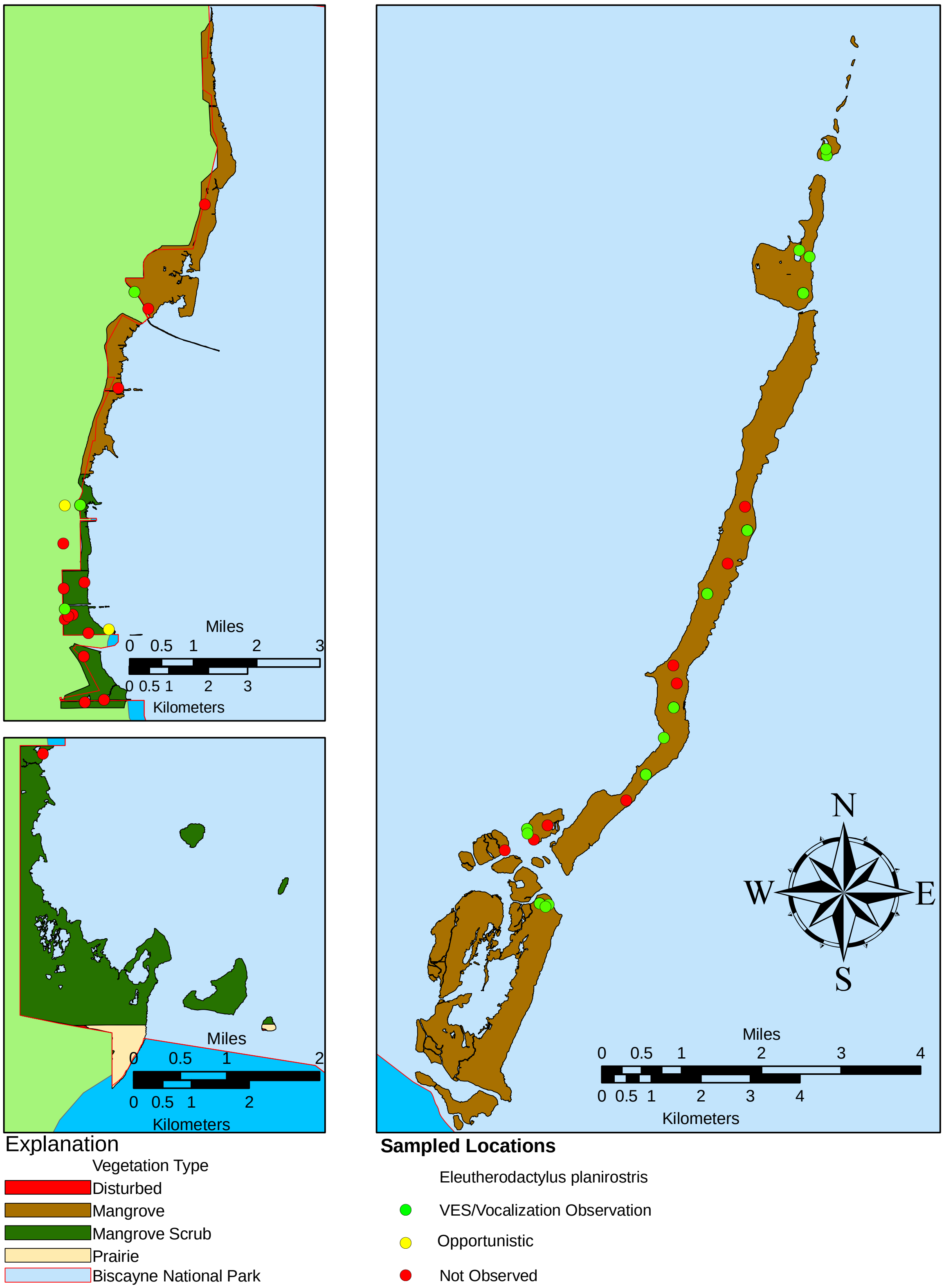


Figure 9. Locations at which *Eleutherodactylus planirostris* were observed at Biscayne National Park.

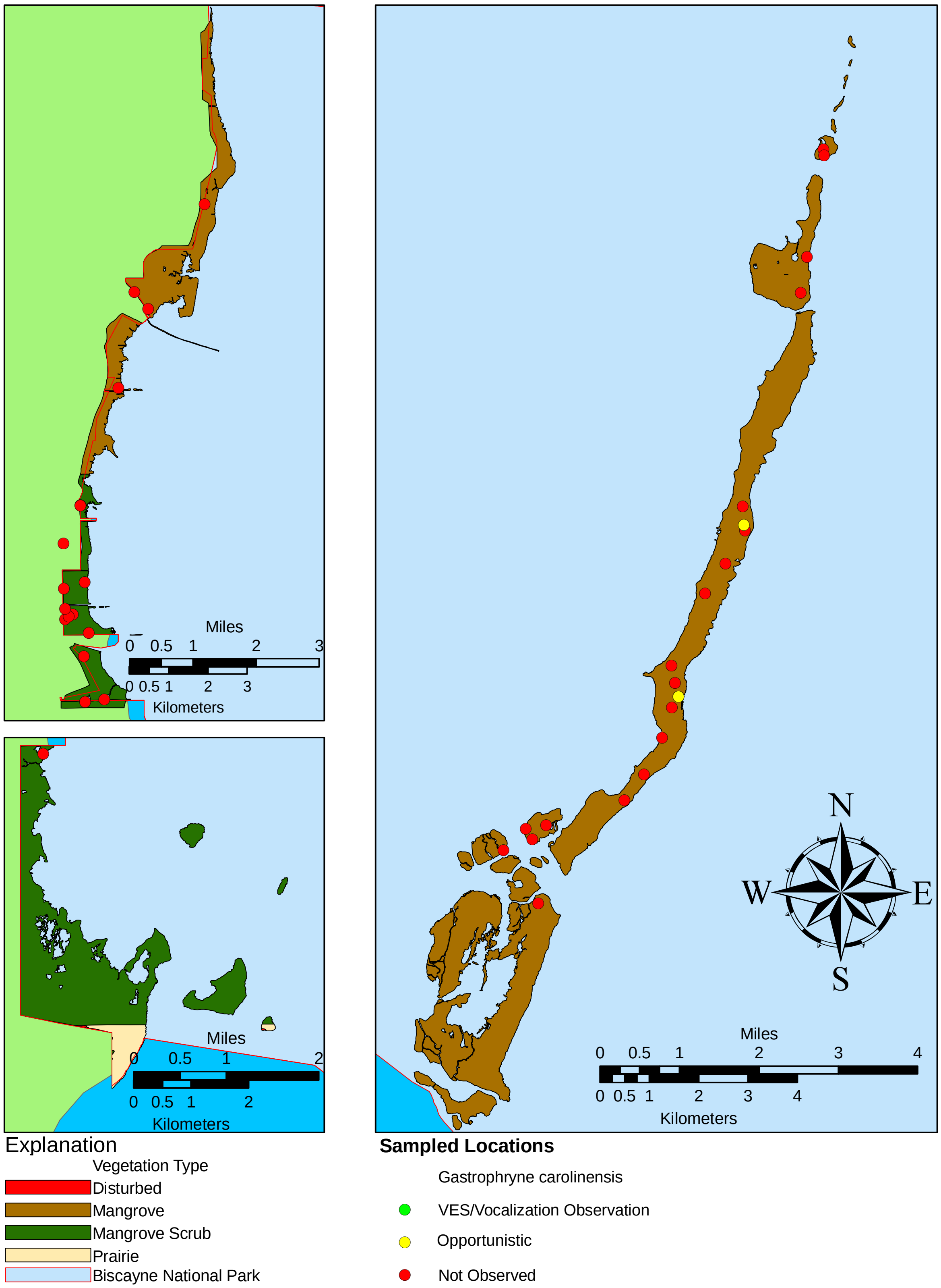


Figure 10. Locations at which *Gastrophryne carolinensis* were observed at Biscayne National Park.

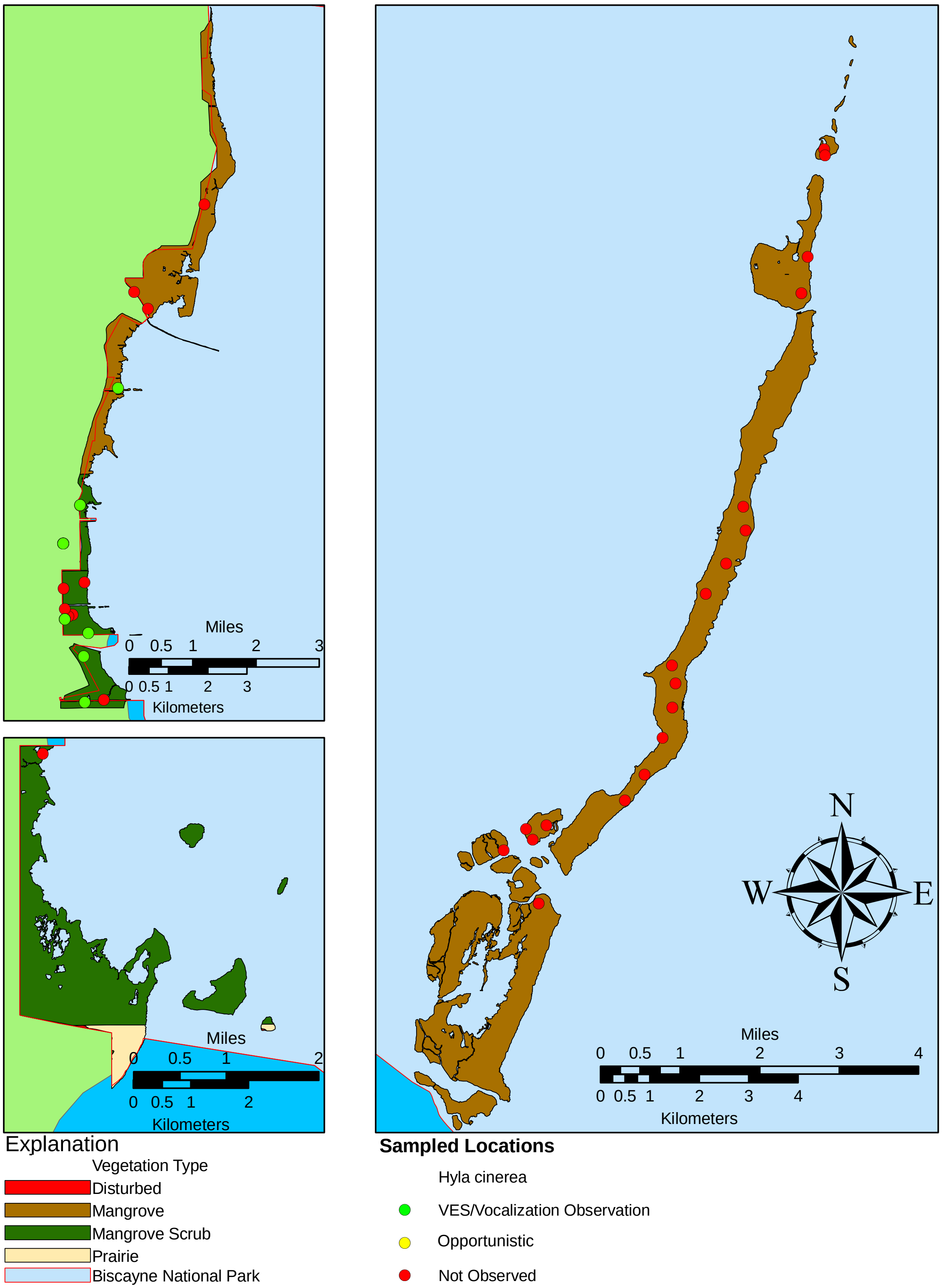


Figure 11. Locations at which *Hyla cinerea* were observed at Biscayne National Park.

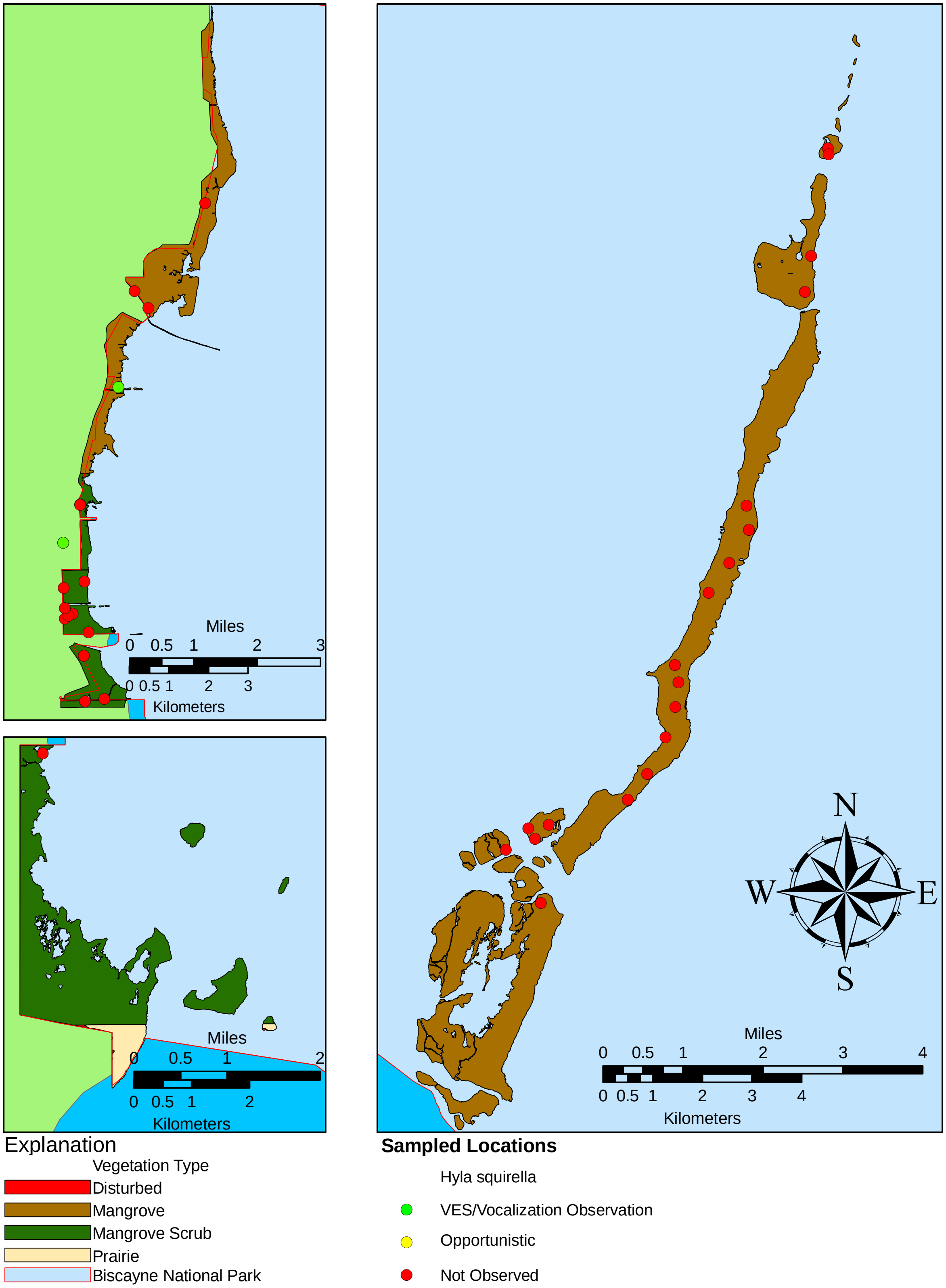


Figure 12. Locations at which *Hyla squirella* were observed at Biscayne National Park.

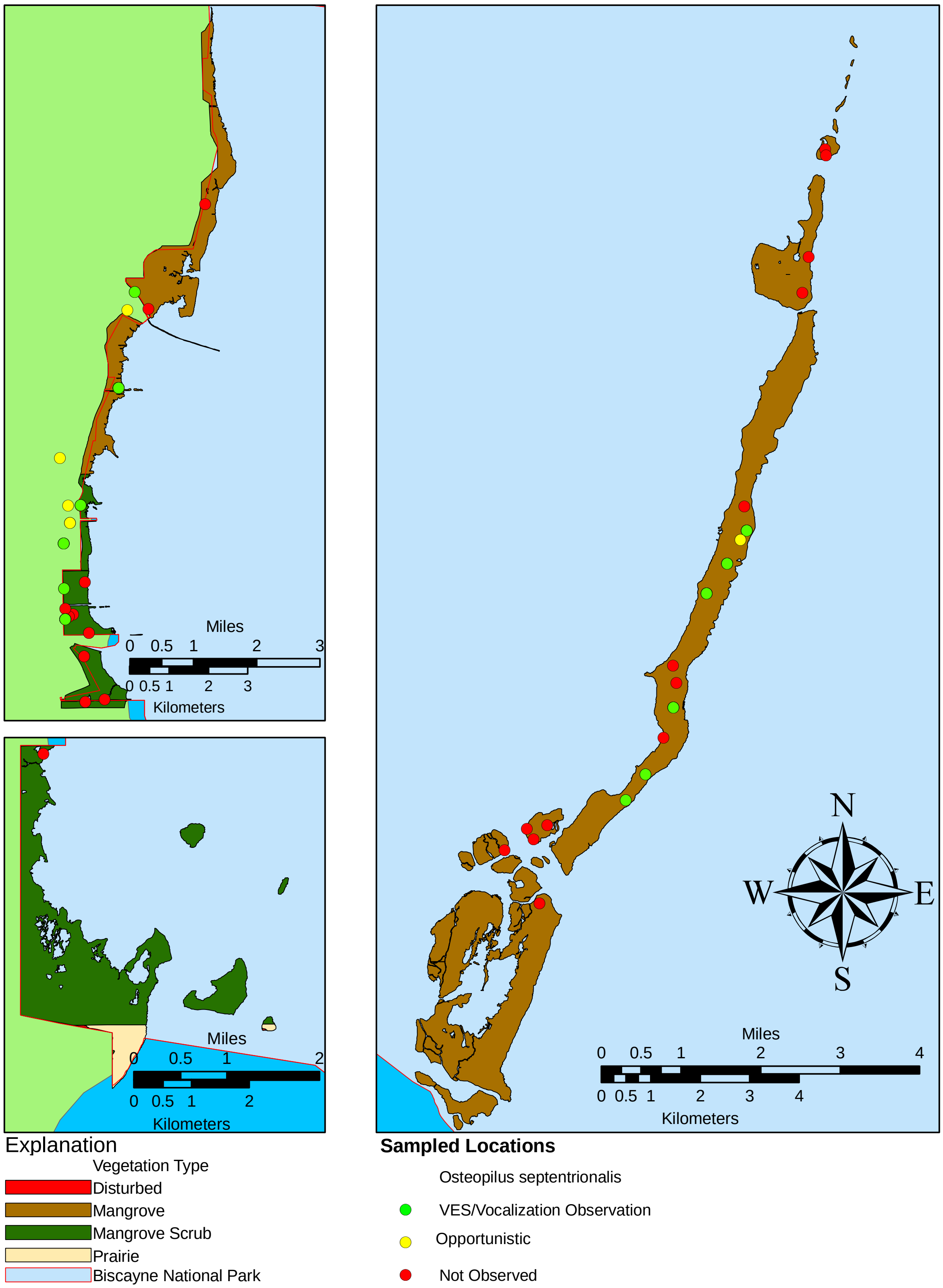


Figure 13. Locations at which *Osteopilus septentrionalis* were observed at Biscayne National Park.

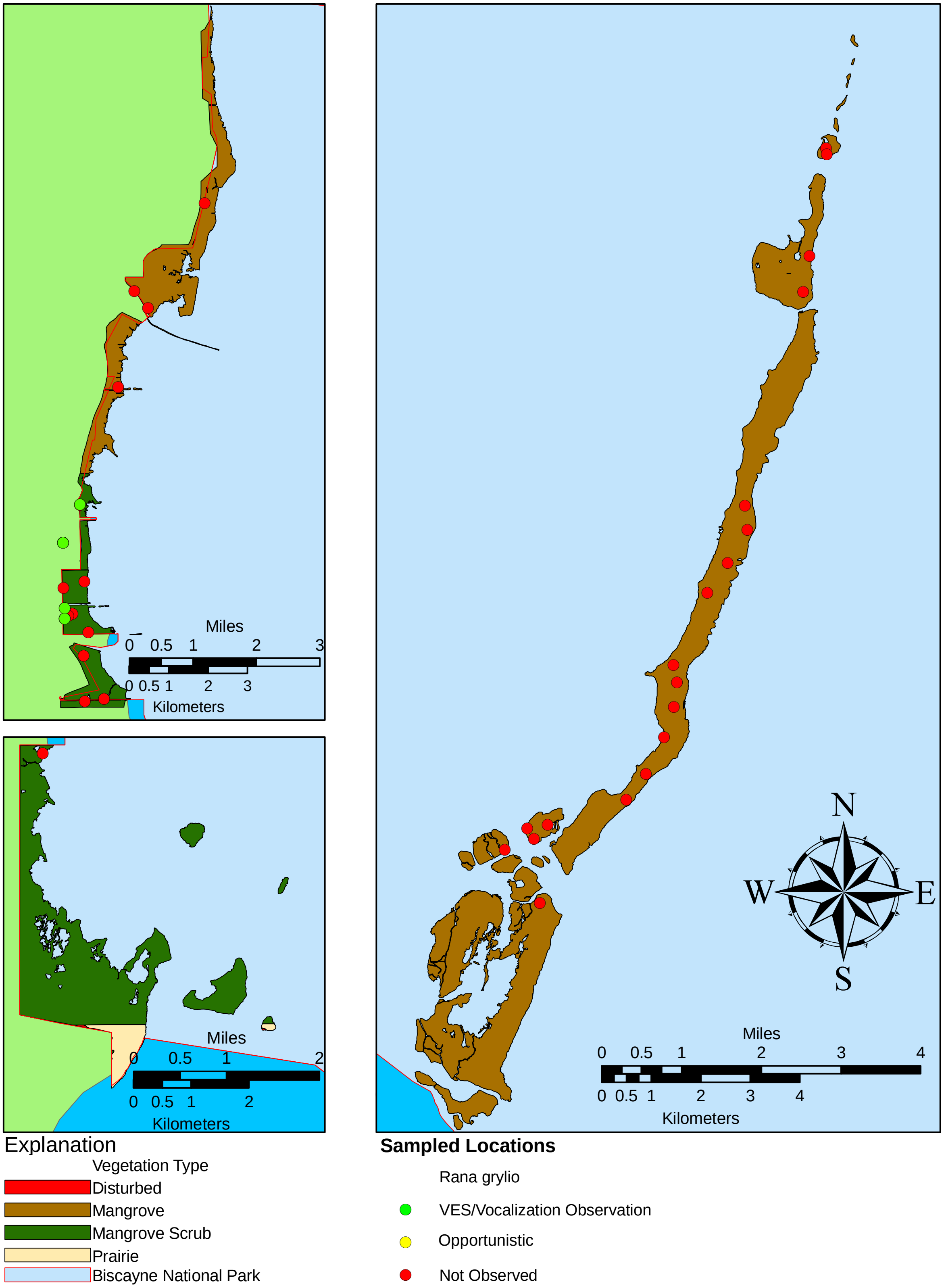


Figure 14. Locations at which *Rana grylio* were observed at Biscayne National Park.

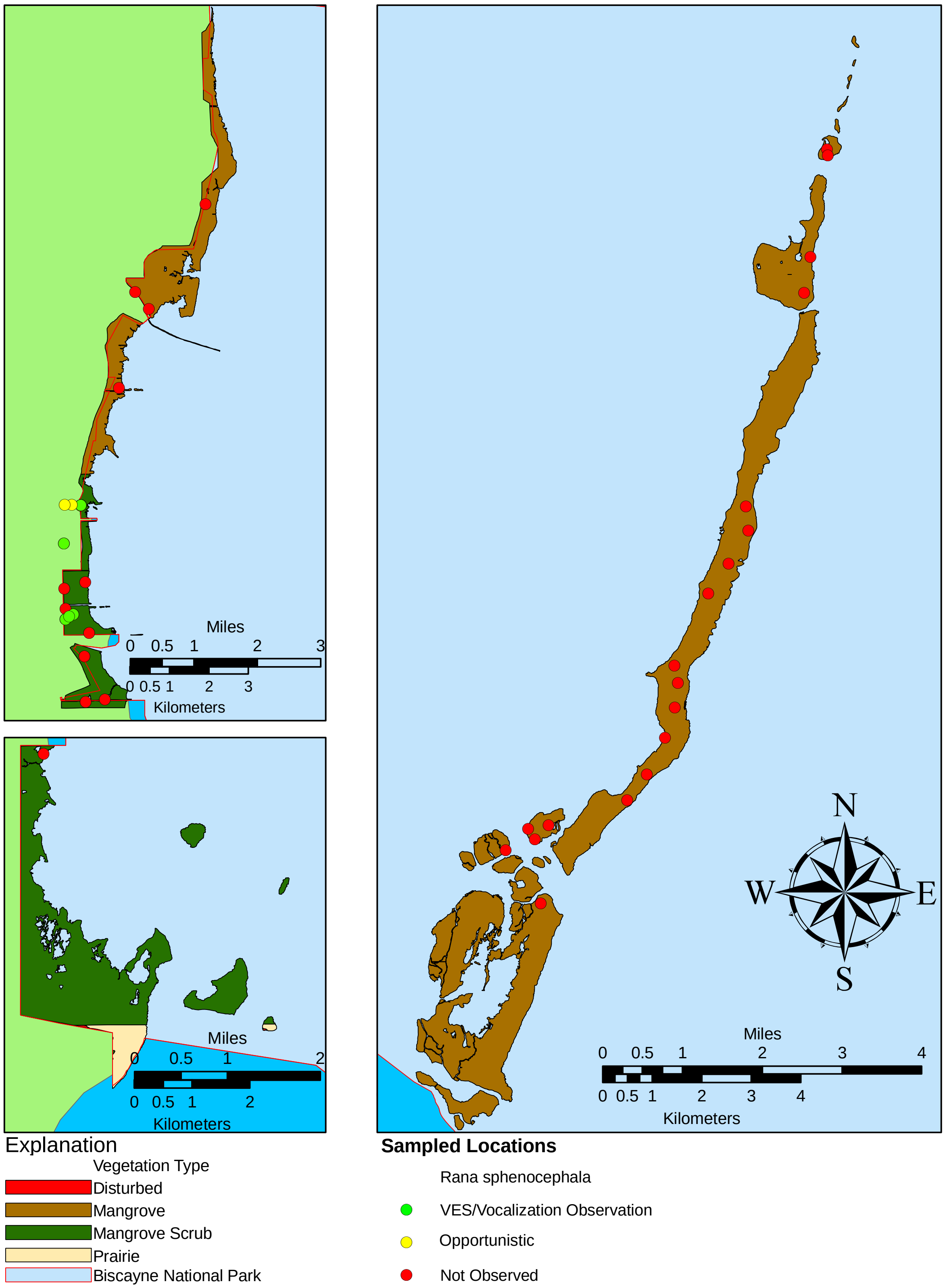


Figure 15. Locations at which *Rana sphenocephala* were observed at Biscayne National Park.

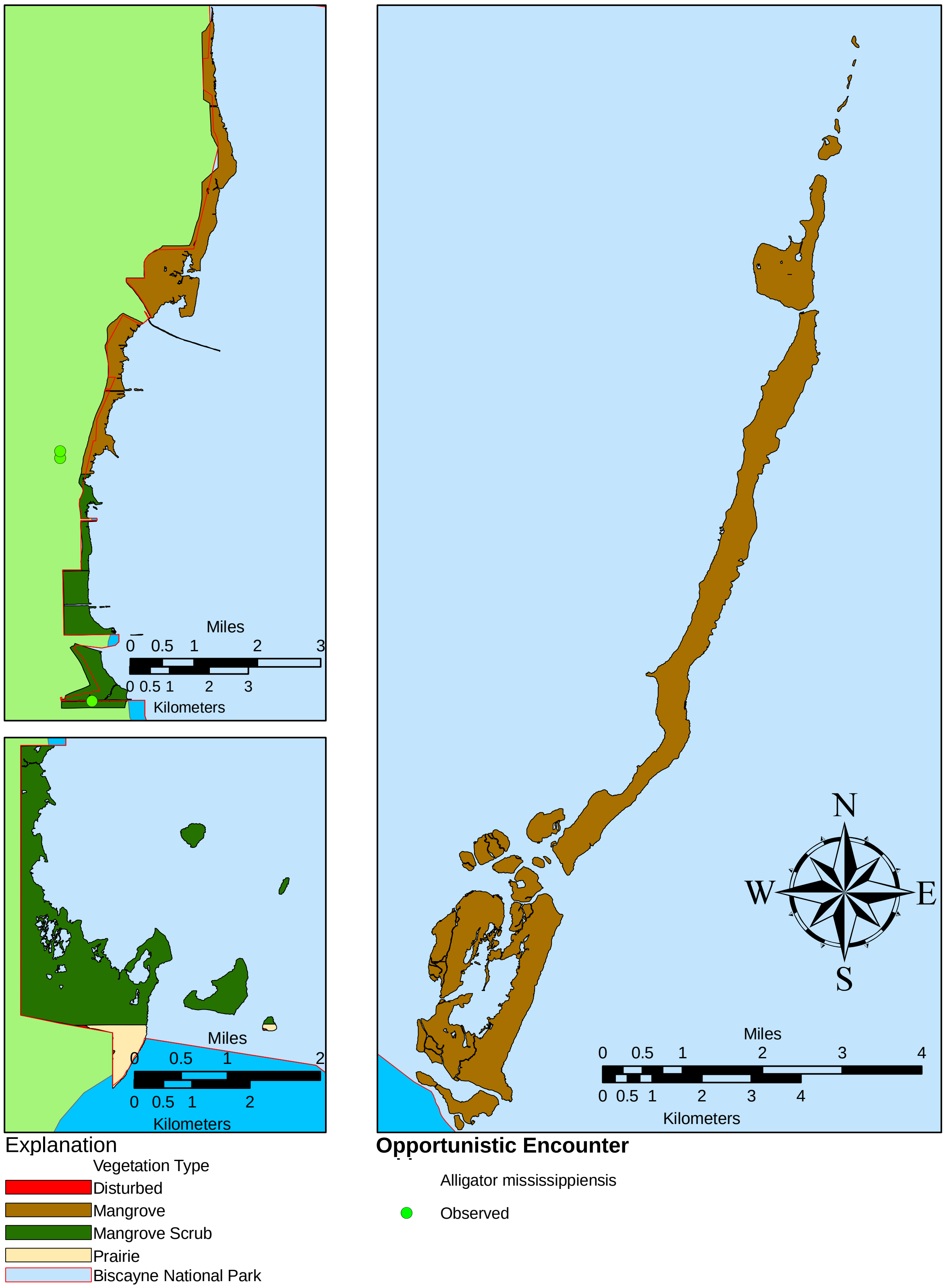


Figure 16. Locations at which *Alligator mississippiensis* were observed at Biscayne National Park.

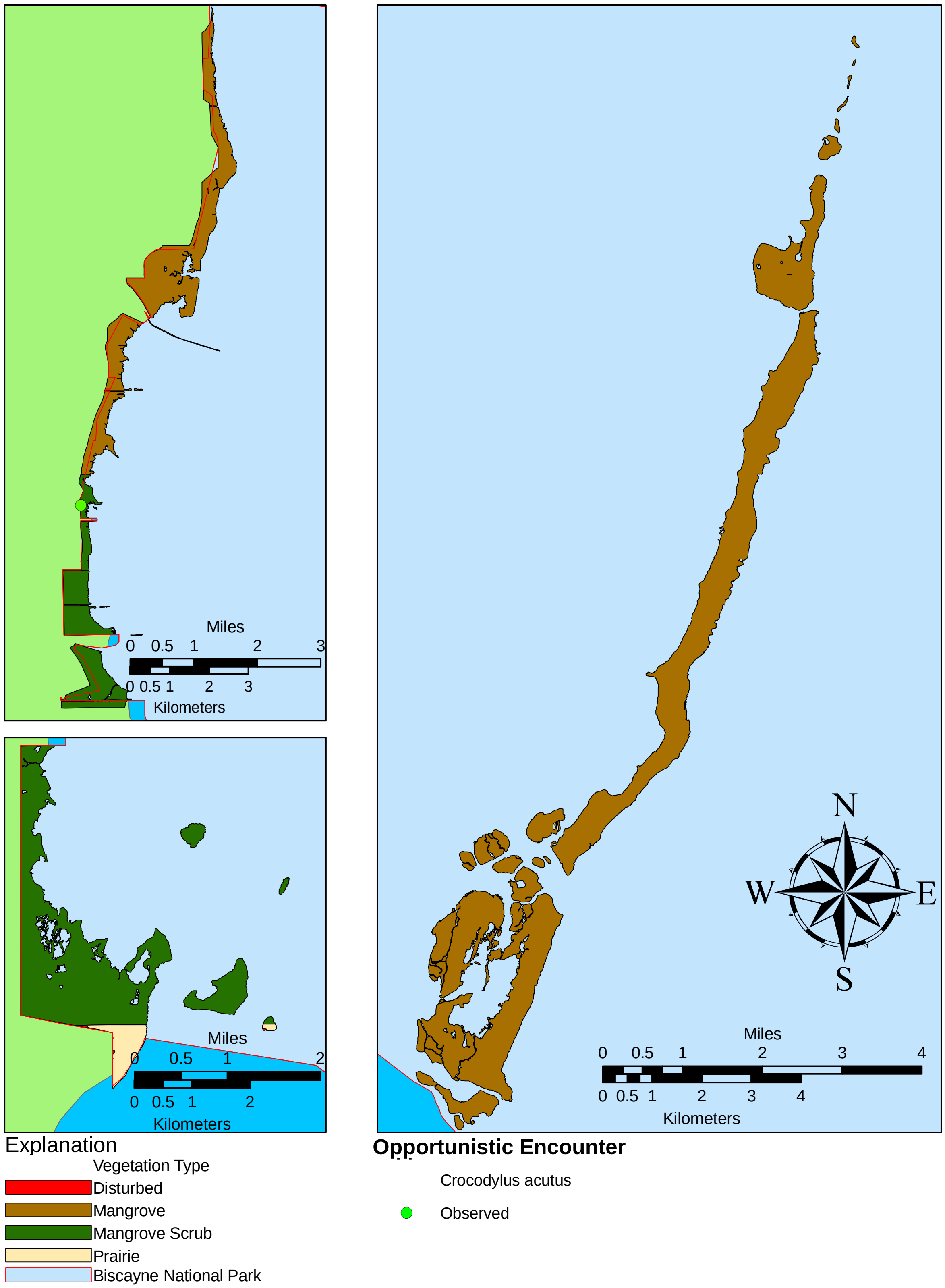


Figure 17. Locations at which *Crocodylus acutus* were observed at Biscayne National Park.

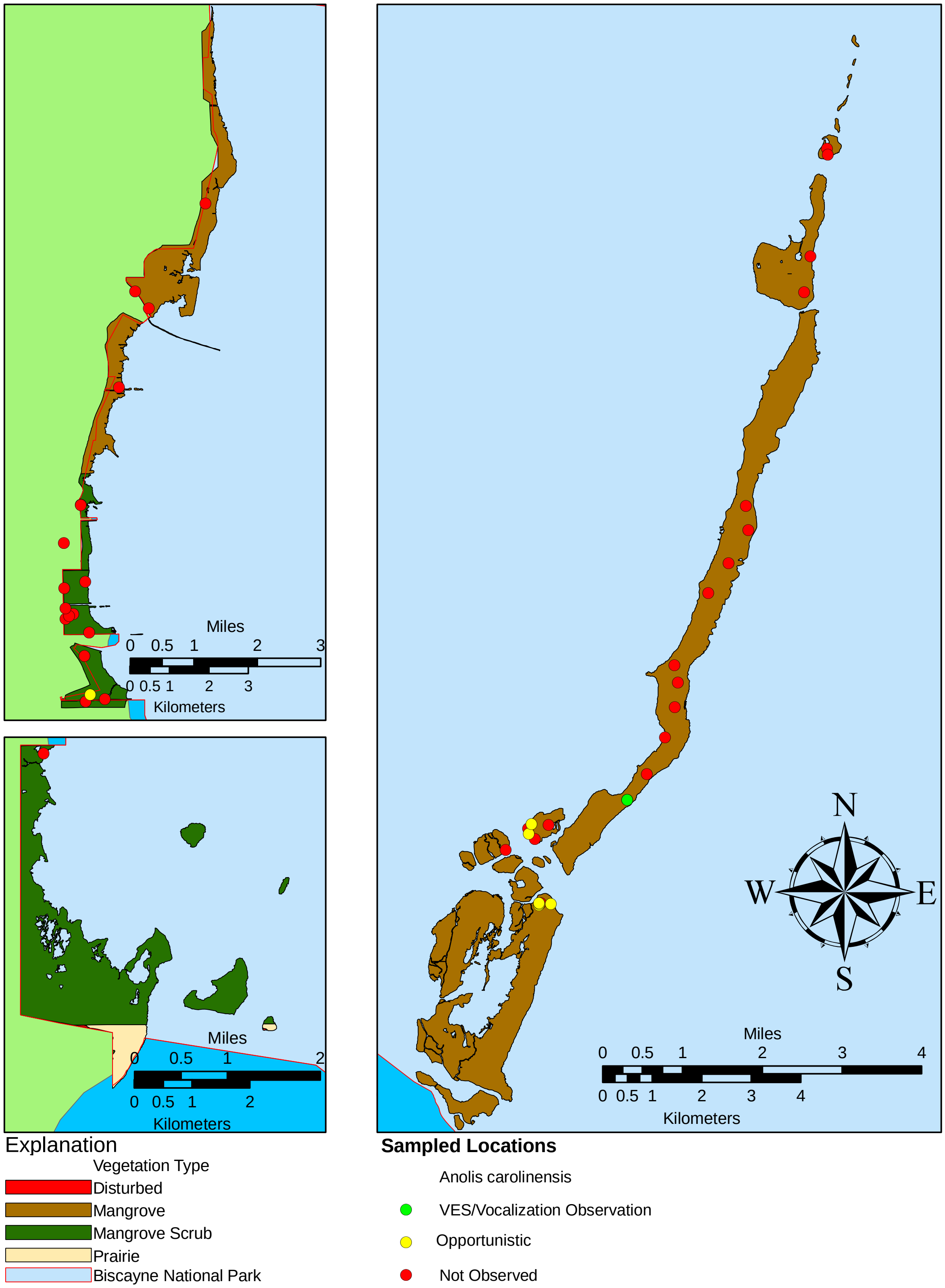


Figure 18. Locations at which *Anolis carolinensis* were observed at Biscayne National Park.

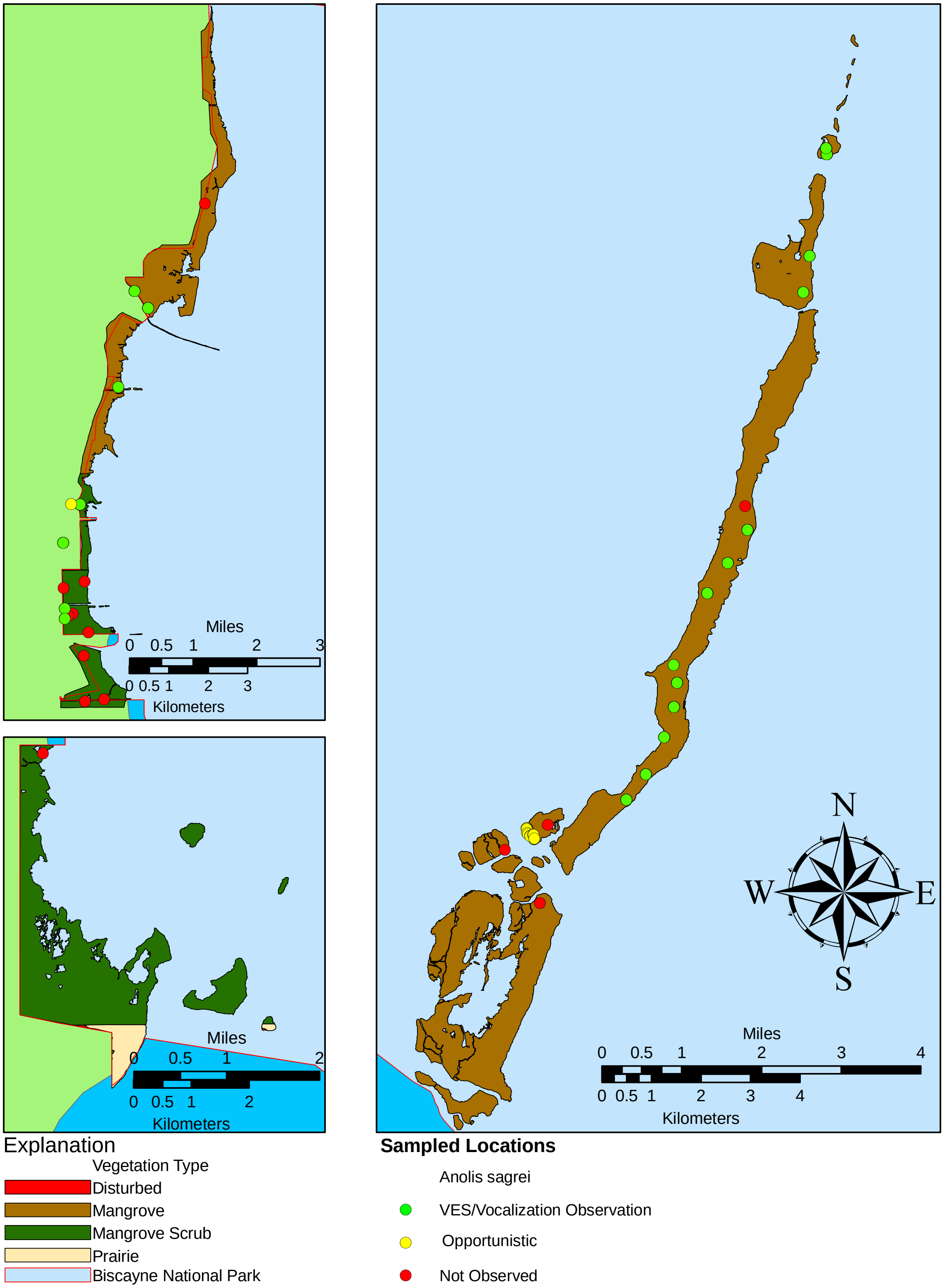


Figure 19. Locations at which *Anolis sagrei* were observed at Biscayne National Park.

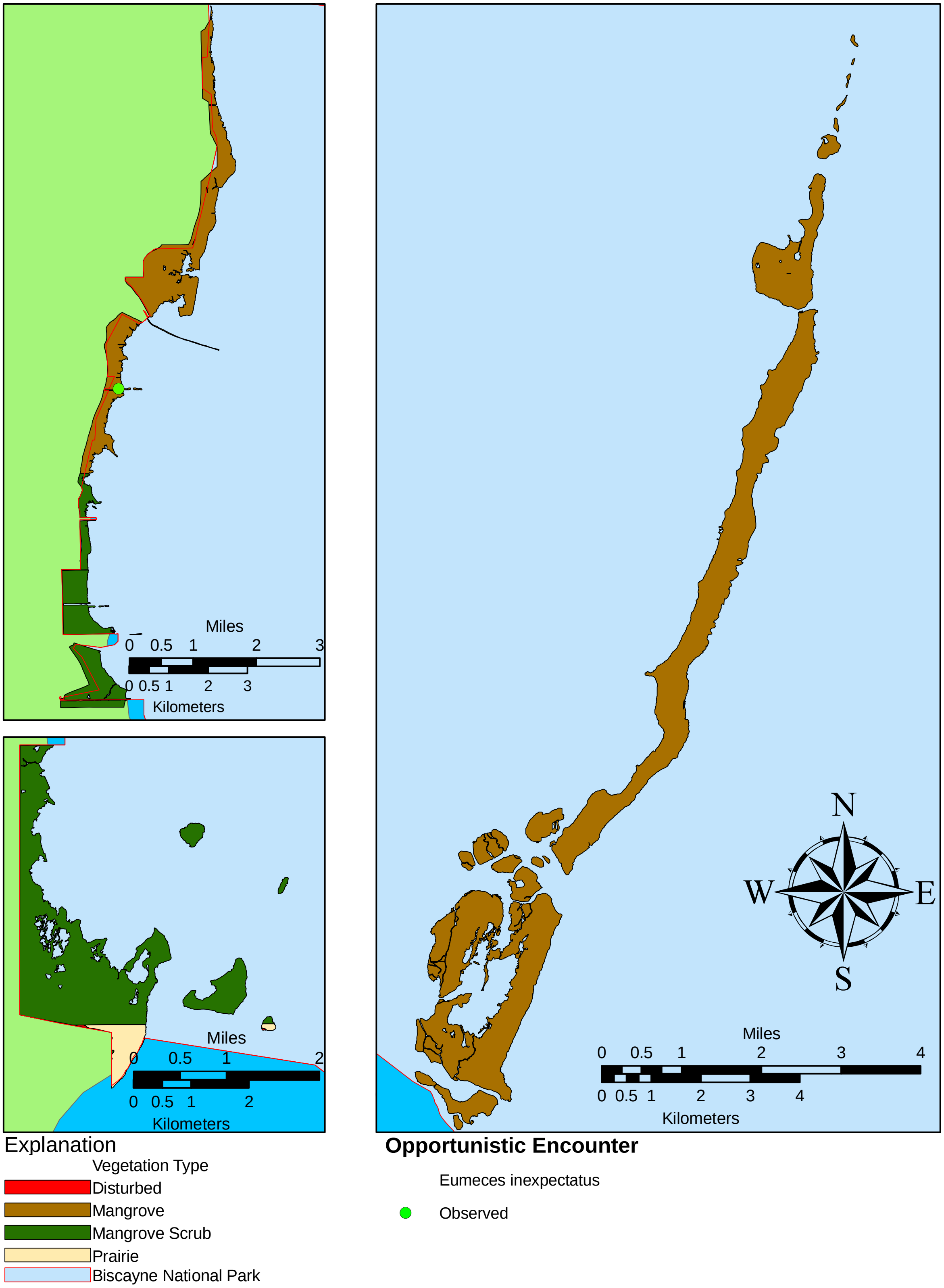


Figure 20. Locations at which *Eumeces inexpectatus* were observed at Biscayne National Park.

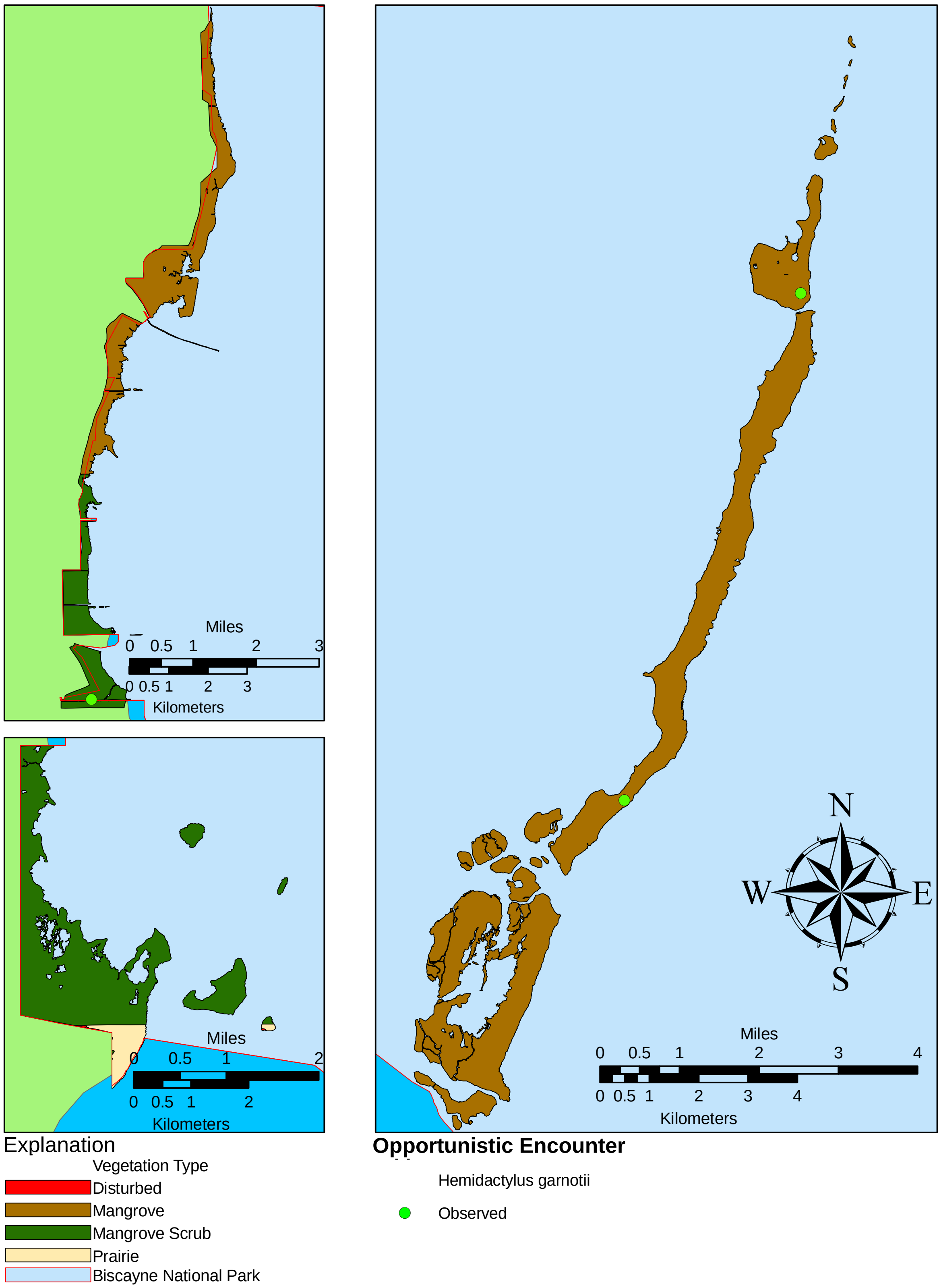


Figure 21. Locations at which *Hemidactylus garnotii* were observed at Biscayne National Park.

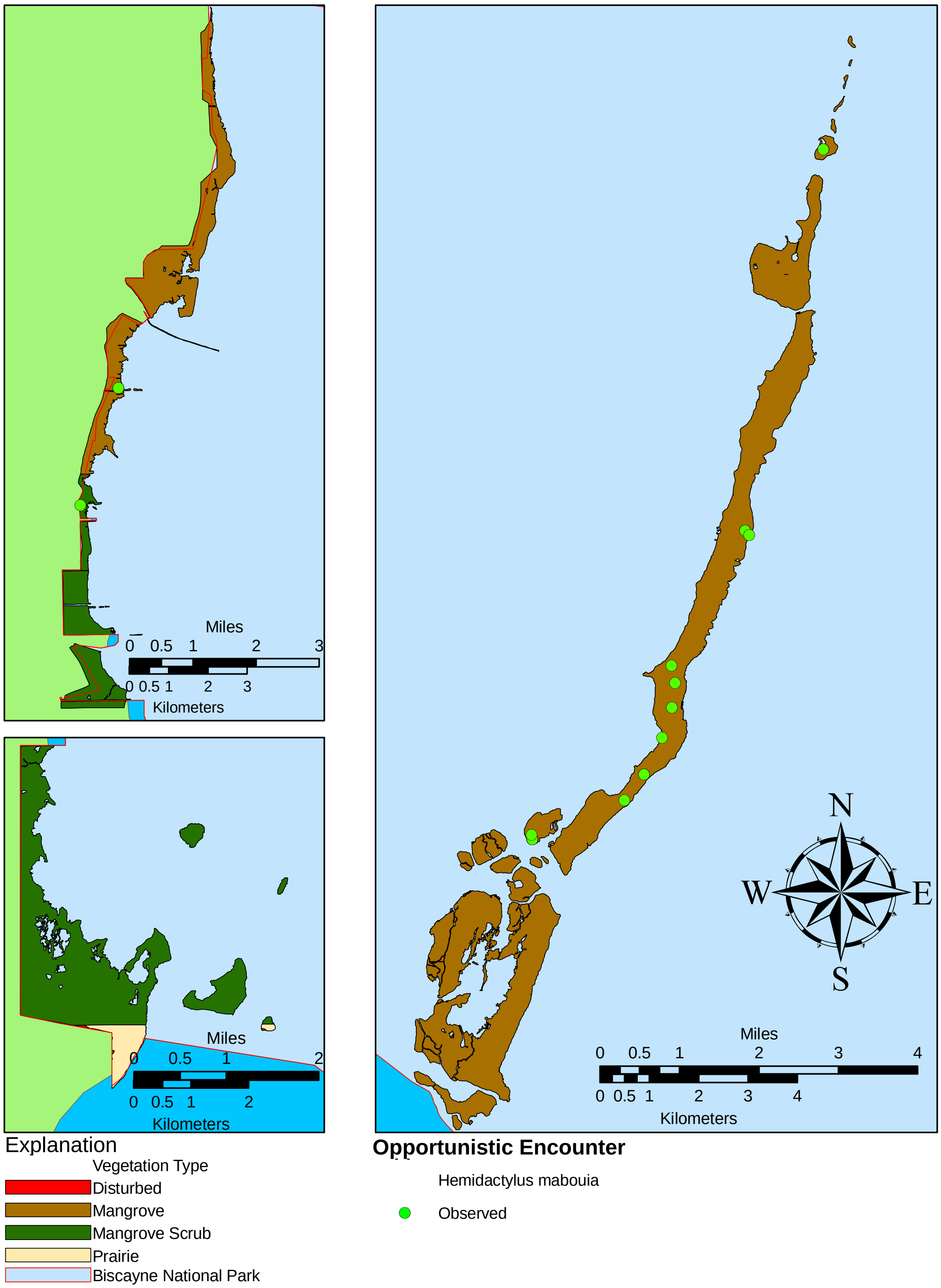


Figure 22. Locations at which *Hemidactylus mabouia* were observed at Biscayne National Park.

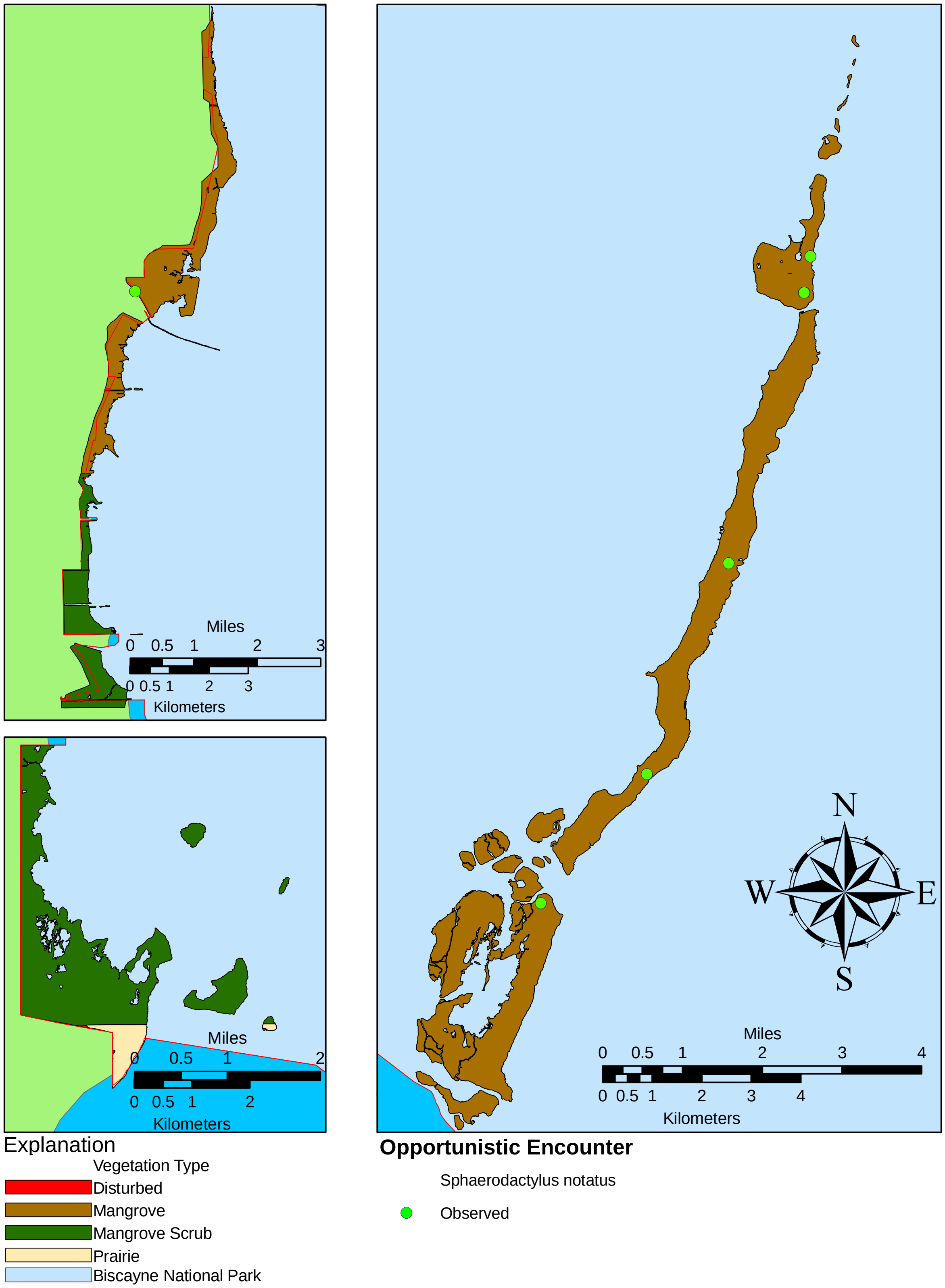


Figure 23. Locations at which *Sphaerodactylus notatus* were observed at Biscayne National Park.

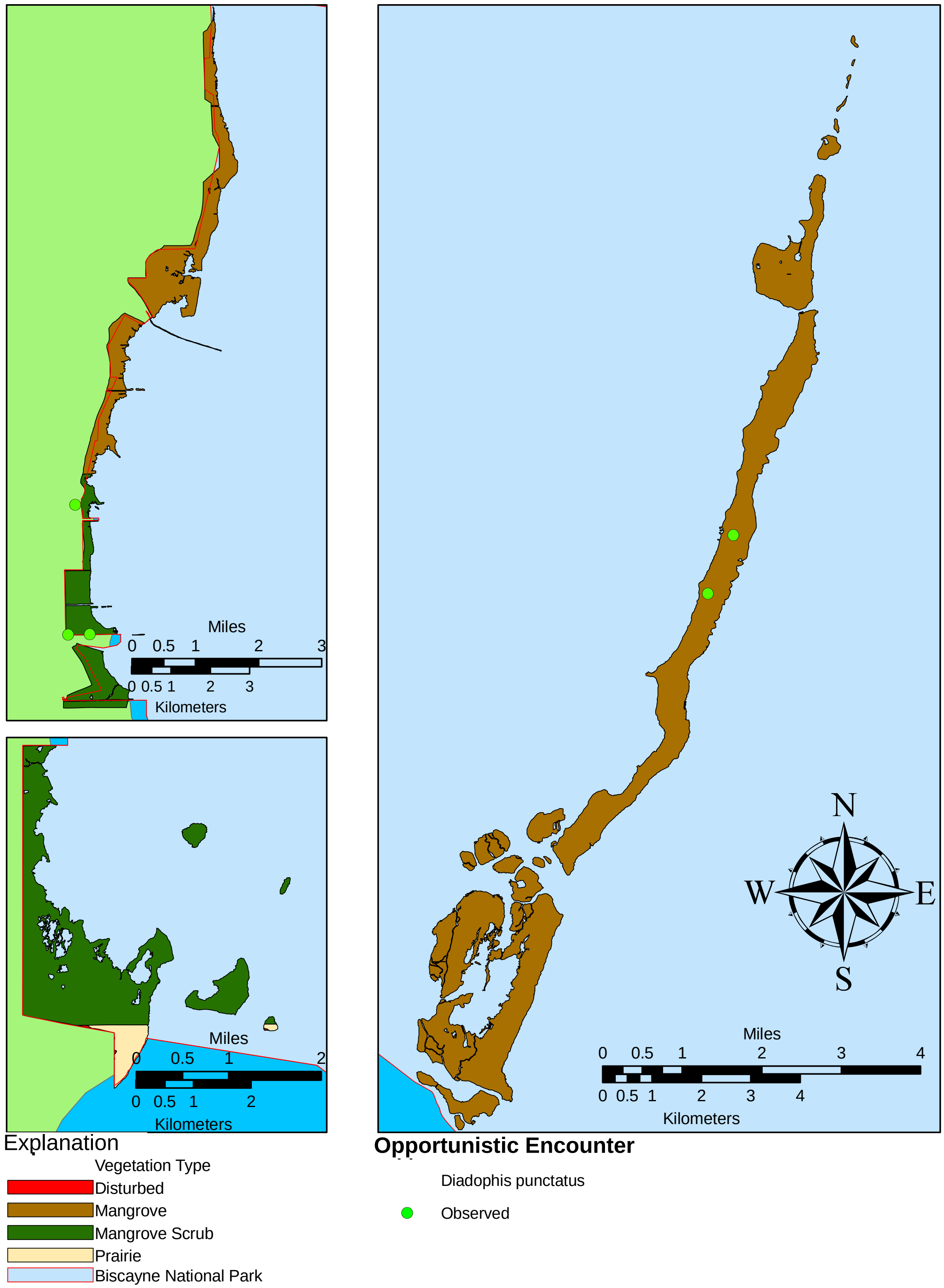


Figure 24. Locations at which *Diadophis punctatus* were observed at Biscayne National Park.

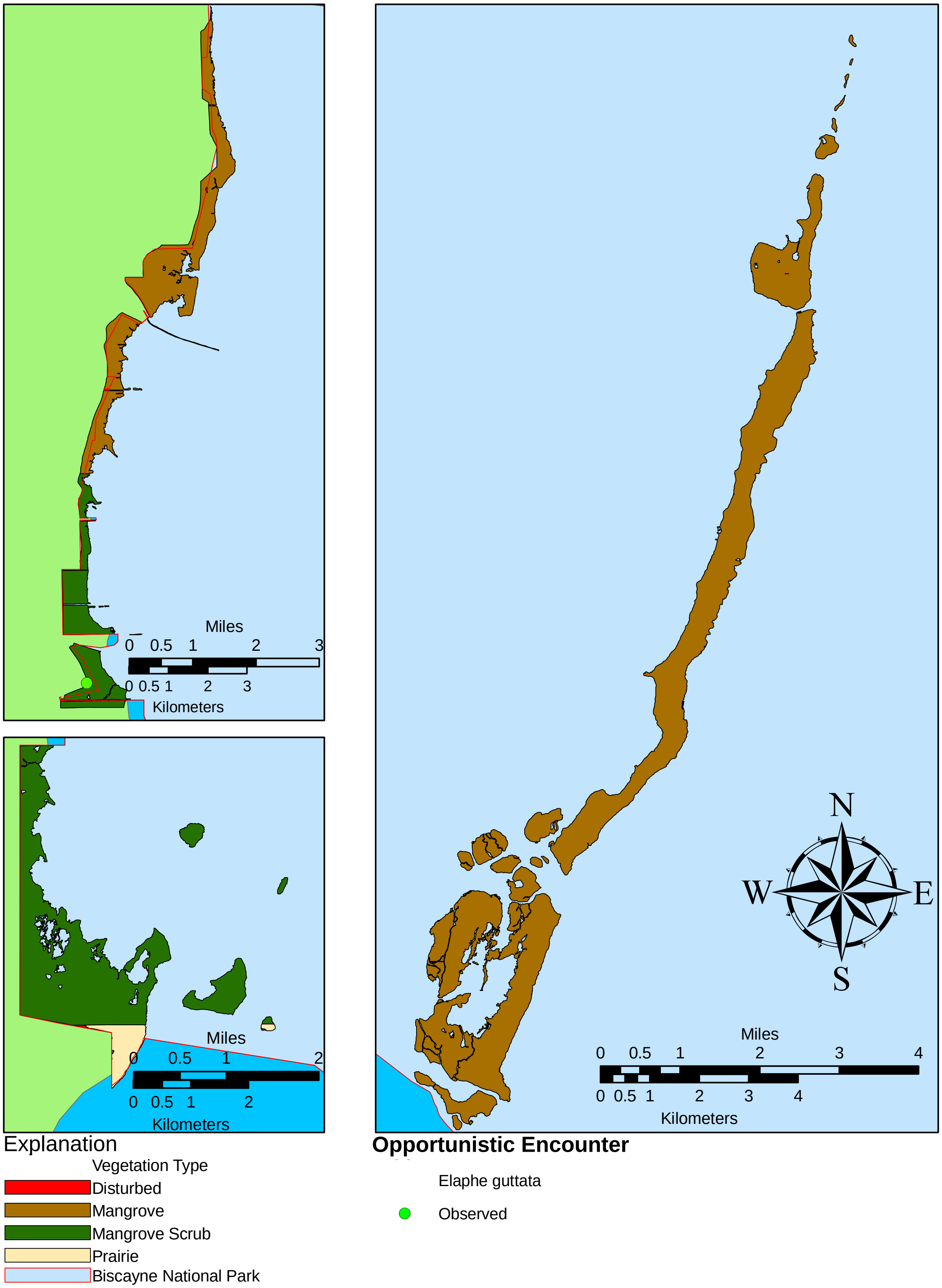


Figure 25. Locations at which *Elaphe guttata* were observed at Biscayne National Park.

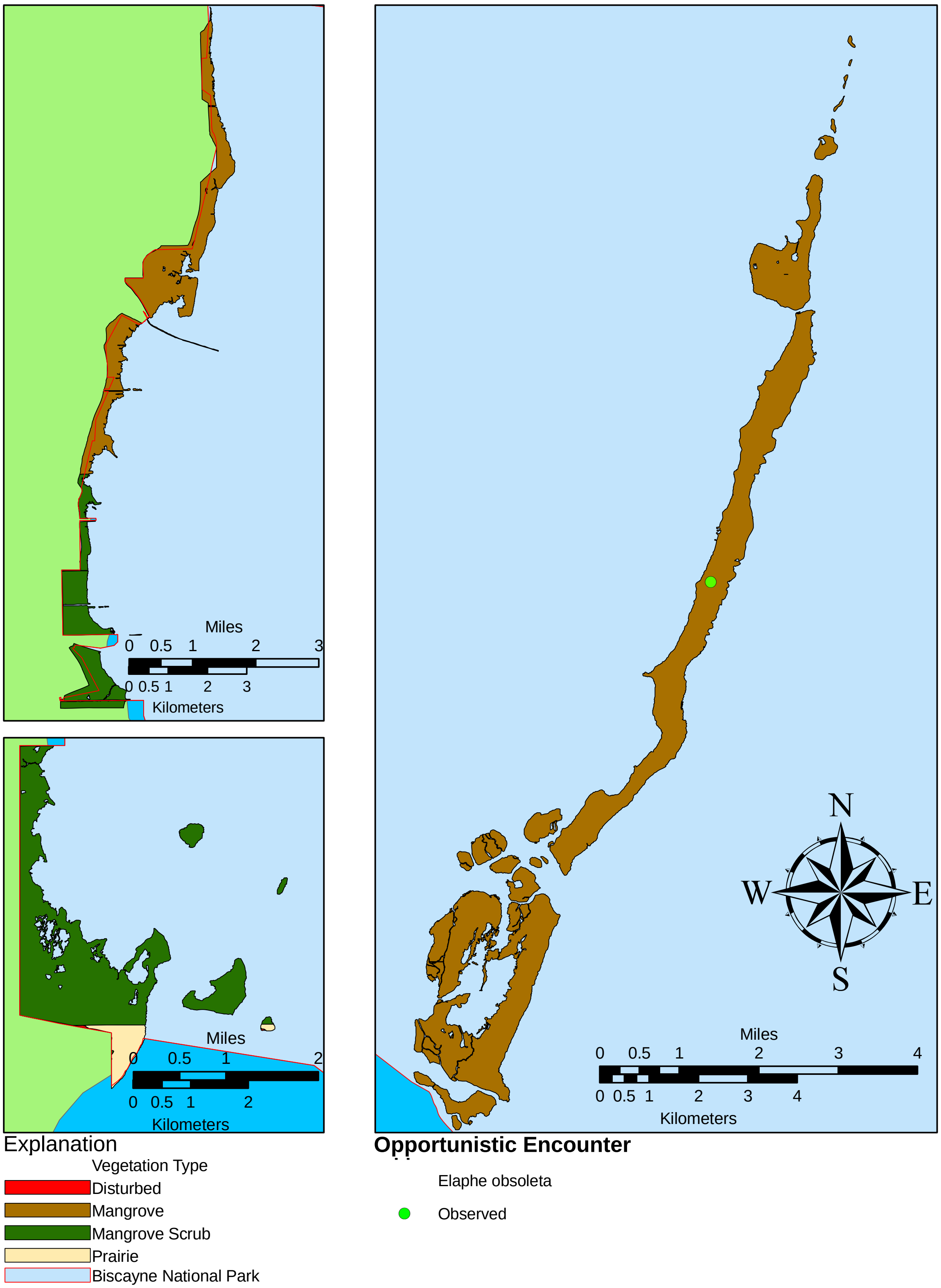


Figure 26. Locations at which *Elaphe obsoleta* were observed at Biscayne National Park.

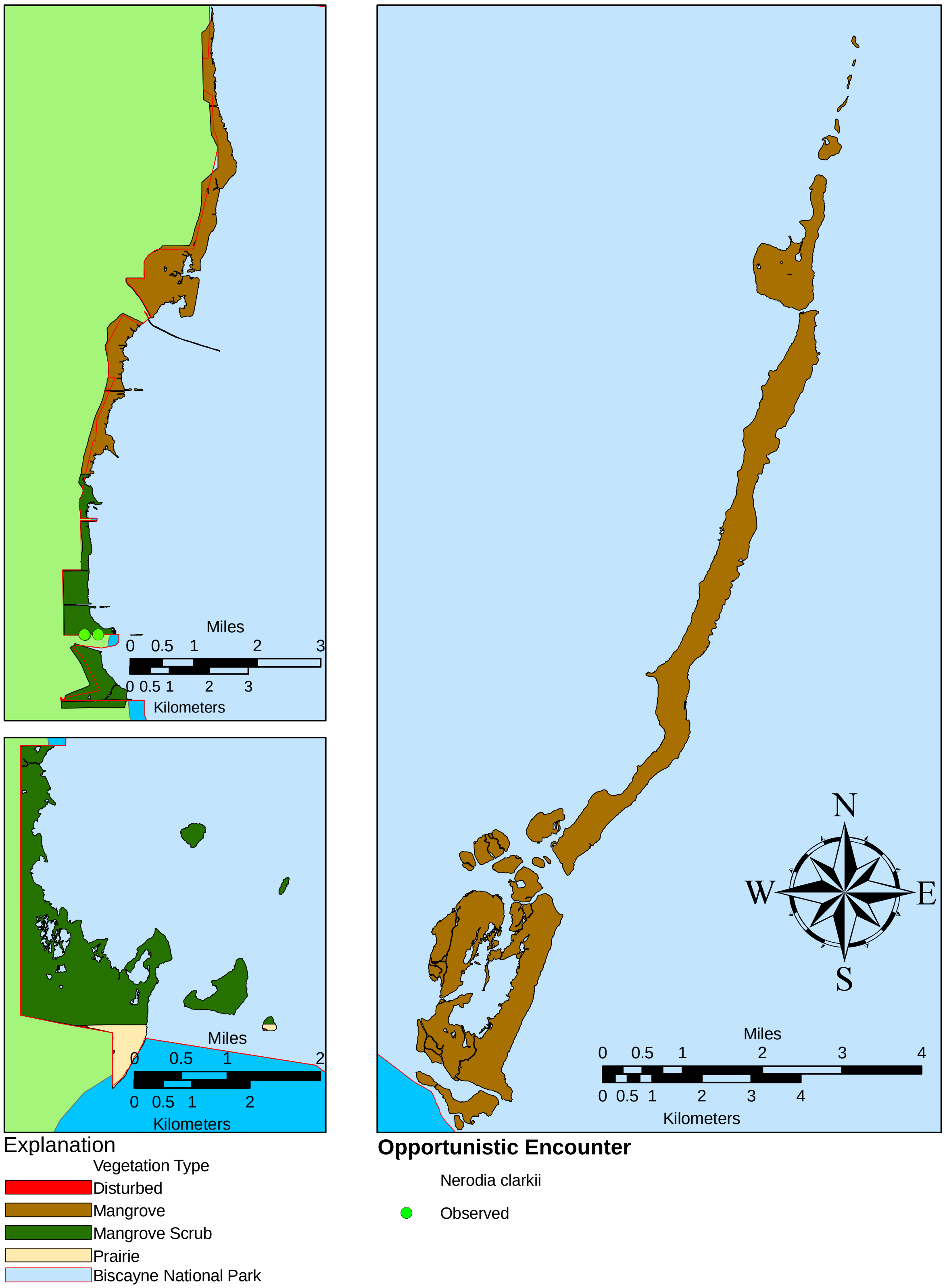


Figure 27. Locations at which *Nerodia clarkii* were observed at Biscayne National Park.

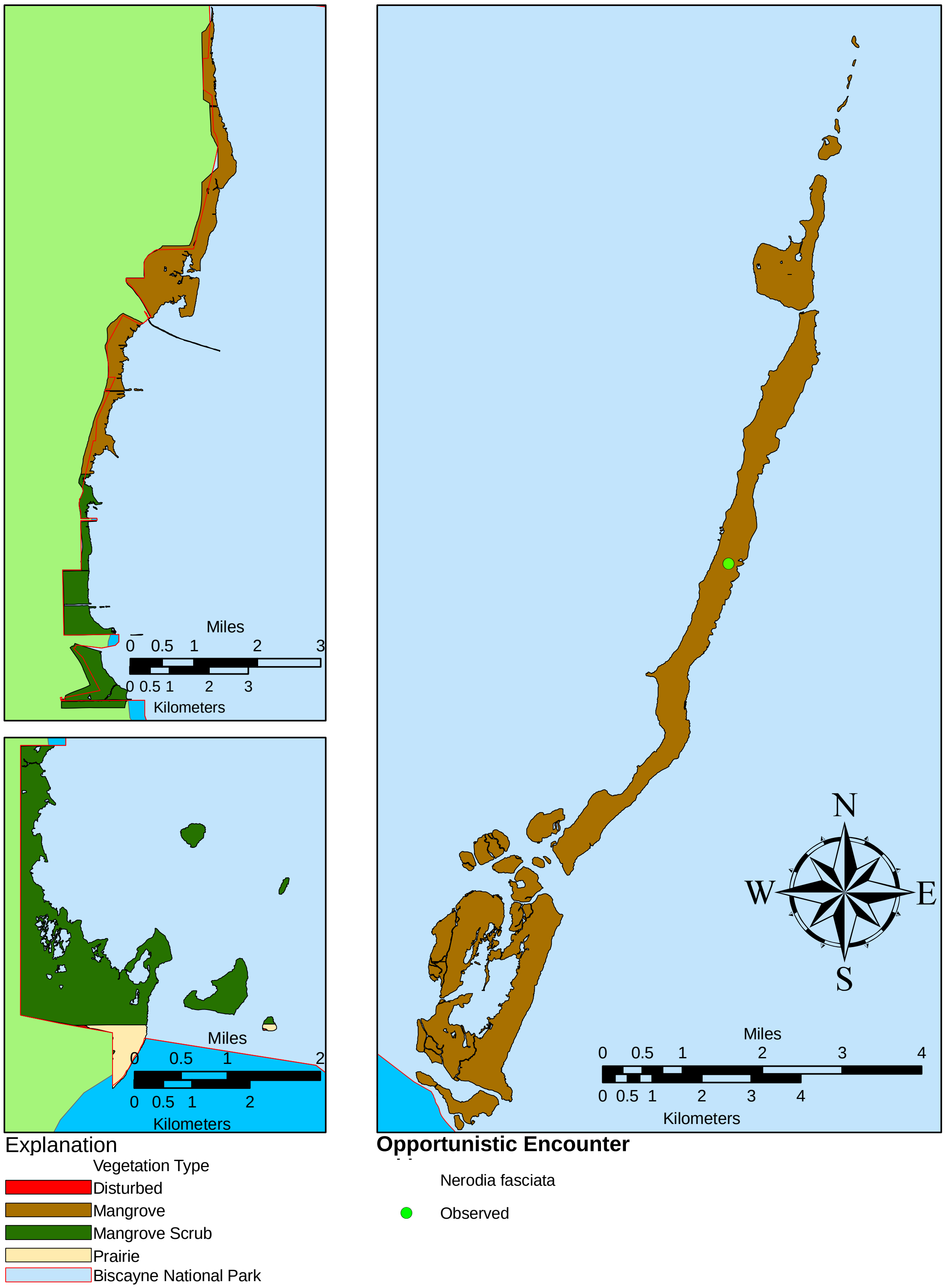


Figure 28. Locations at which *Nerodia fasciata* were observed at Biscayne National Park.

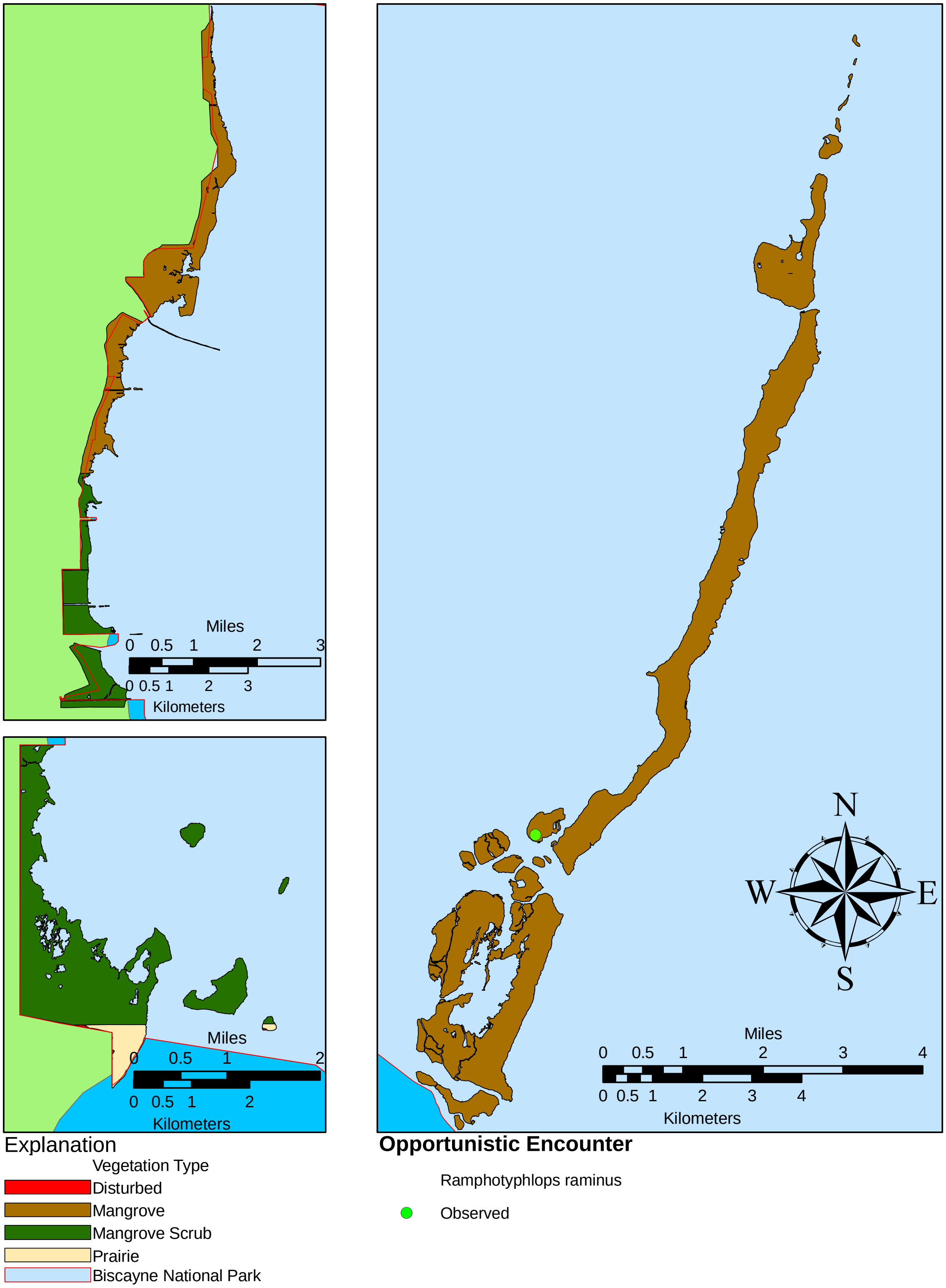


Figure 29. Locations at which *Ramphotyphlops raminus* were observed at Biscayne National Park.

Table 1. Vegetation classification of Key Biscayne National Park.

CODE	Description	BISC Vegetation Classification
BCH	Beach	
C	Canal	
E	Exotic	Disturbed
EA	Shoebutton Ardisia (*Ardisia elliptica*)	Disturbed
EC	Australian Pine (*Casuarina* spp.)	Disturbed
EJ	Java Plum (*Syzygium cuminii*)	Disturbed
EL	Tropical Soda Apple (*Solanum viarum*)	Disturbed
EM	Cajeput (*Melaleuca quinquenervia*)	Disturbed
EO	Lather Leaf (*Colubrina asiatica*)	Disturbed
ES	Brazilian Pepper (*Schinus terebinthifolius*)	Disturbed
F	Forest	Hammock
FB	Buttonwood Forest (*Conocarpus erectus*)	Hammock
FC	Cabbage Palm Forest (*Sabal palmetto*)	Hammock
FM	Mangrove Forest	Mangrove
FMa	Black (*Avicennia germinans*)	Mangrove
FMl	White (*Laguncularia racemosa*)	Mangrove
FMr	Red (*Rhizophora mangle*)	Mangrove
FMx	Mixed Mangroves	Mangrove
FO	Oak-Sabal Forest	Hammock
FP	Paurotis Palm Forest (*Acoelorrhaphe wrightii*)	Hammock
FS	Swamp Forest	Hammock
FSCpi	Cypress-Pines	
FSa	Mixed Hardwood , Cypress , Pine	Hammock
FSb	Bayhead	Hammock
FSbc	Cocoplum	Hammock
FSc	Cypress Strand/Head	
FSd	Cypress Dome	
FSh	Mixed Hardwood	Hammock
FSx	Mixed Hardwood , Cypress	Hammock
FT	Subtropical Hardwood Forest	Hammock
HI	Human Influence	Disturbed
HIp	Pumping Station	Disturbed
MUD	Mud	
ORV	Off Road Vehicle Trails	Disturbed
P	Prairie / Marsh	Prairie
PC	Cat-tail	Prairie
PE	Non-graminoid Emergent Marsh	Prairie
PEb	Broadleaf Emergents	Prairie
PG	Graminoid Prairie	Prairie
PGa	Maidencane	Prairie
PGc	Saw Grass (*Cladium jamaicense*)	Prairie

Table 1. Vegetation classification of Key Biscayne National Park-Continued

PGct	Tall Saw Grass	Prairie
PGe	Spike-rush (*Eleocharis cellulosa*)	Prairie
PGj	Black-rush (*Juncus roemerianus*)	Prairie
PGm	Muhly	Prairie
PGp	Common Reed (*Phragmites* spp.)	Prairie
PGs	Cord Grass (*Spartina* spp.)	Prairie
PGw	Maidencane / Spike-rush	Prairie
PGx	Mixed Graminoids	Prairie
PH	Halophytic Herbaceous Prairie	Prairie
PHg	Graminoid	Prairie
PHs	Succulent	Prairie
PND	Pond	
PPI	Prairie with Scattered Pine	Prairie
PR	Pinnacle Rock	
RD	Road	Disturbed
S	Scrub	Hammock
SA	Spoil Area	Disturbed
SB	Shrubland	Hammock
SBb	Groundsel Bush (*Baccharis* spp.)	Hammock
SBc	Buttonbush (*Cephalanthus occidentalis*)	Hammock
SBf	Pop Ash (*Fraxinus caroliniana*)	Hammock
SBl	Primrose (*Ludwigia* spp.)	Hammock
SBm	Wax Myrtle (*Myrica cerifera*)	Hammock
SBs	Willow (*Salix caroliniana*)	Hammock
SBy	Cocoplum (*Chrysobalanus icaco*)	Hammock
SC	Buttonwood Scrub (*Conocarpus erectus*)	Mangrove Scrub
SH	Hardwood Scrub	Mangrove Scrub
SM	Mangrove Scrub	Mangrove Scrub
SMa	Black (*Avicennia germinans*)	Mangrove Scrub
SMl	White (*Laguncularia racemosa*)	Mangrove Scrub
SMr	Red (*Rhizophora mangle*)	Mangrove Scrub
SMx	Mixed Mangroves	Mangrove Scrub
SP	Saw Palmetto Scrub	Hammock
SS	Bay-Hardwood Scrub	Hammock
SV	Savanna	Prairie
SVC	Cypress Savanna	
SVCd	Dwarf Cypress	
SVCpi	Cypress with Pine	
SVPI	Pine Savanna	
SVPIc	Slash Pine with Cypress	
SVPIh	Slash Pine with Hardwood	
SVx	Slash Pine with Palm	
SVPM	Palm Savanna	Hammock
W	Water	

Table 2. The 14 models evaluated for most amphibian species to determine the estimate of proportion of area occupied (Psi) and detection probability (p).

Model Description	Site Covariates	Sampling Occasion Covariates
Psi(.); p(.)	Constant	Constant
Psi(.); p(humid)	Constant	Relative Humidity
Psi(.); p(temp)	Constant	Air Temperature
Psi(.); p(temp, humid)	Constant	Air Temperature and Relative Humidity
Psi(.); p(temp, humid, water)	Constant	Air Temperature, Relative Humidity, and Presence of Water
Psi(.); p(temp, water)	Constant	Air Temperature and Presence of Water
Psi(.); p(water)	Constant	Presence of Water
Psi(island); p(.)	Island	Constant
Psi(island); p(humid)	Island	Relative Humidity
Psi(island); p(temp)	Island	Air Temperature
Psi(island); p(temp, humid)	Island	Air Temperature and Relative Humidity
Psi(island); p(temp, humid, water)	Island	Air Temperature, Relative Humidity, and Presence of Water
Psi(island); p(temp, water)	Island	Air Temperature and Presence of Water
Psi(island); p(water)	Island	Presence of Water

Table 3. Location, number of visits, and habitat type of sampled sites. Coordinates are in World Geodetic System (WGS) 1984.

Plot Number	Sampled Monthly	Habitat Type	Island	UTM Easting	UTM Northing
402	X	Hammock	Boca Chita	582892	2822974
401	X	Hammock	Sands Key	582421	2820194
306	X	Mangrove	Elliott Key	581293	2815396
301	X	Mangrove	Mainland	567087	2822677
302	X	Mangrove	Mainland	566112	2819702
303	X	Mangrove	Boca Chita	582877	2823091
305	X	Mangrove	Elliott Key	579251	2810461
307	X	Mangrove	Sands Key	582543	2820924
304	X	Mangrove	Elliott Key	580487	2814119
202	X	Prairie	Elliott Key	579871	2812313
201	X	Prairie	Elliott Key	578855	2809952
105	X	Mangrove scrub	Elliott Key	580896	2814731
104	X	Mangrove scrub	Elliott Key	579809	2811817
103	X	Mangrove scrub	Elliott Key	579614	2811208
102	X	Mangrove scrub	Mainland	565728	2816804
101	X	Mangrove scrub	Mainland	565691	2818731
256		Disturbed	Adams Key	576858	2809369
111		Hammock	Old Rhodes Key	577110	2807865
145		Mangrove	Adams Key	577268	2809440
166		Mangrove	Mainland	569272	2827346
182		Mangrove	Mainland	567496	2825117
195		Mangrove	Mainland	567633	2811351
214		Mangrove	Adams Key	576988	2809158
252		Mangrove	Old Rhodes Key	576402	2808943
499		Mangrove	Elliott Key	581246	2815877
300		Mangrove	Mainland	565925	2816925
308		Mangrove	Elliott Key	579801	2812668
385		Mangrove	Mainland	566222	2817745
399		Mangrove	Mainland	566113	2819691
234		Mangrove	Mainland	567837	2824690
23		Mangrove scrub	Mainland	566329	2816456
143		Mangrove scrub	Mainland	566201	2815861
123		Mangrove scrub	Mainland	566232	2814697
310		Mangrove scrub	Mainland	565814	2816878
485		Mangrove scrub	Mainland	565697	2817584
497		Mangrove scrub	Mainland	565728	2817068
65		Mangrove scrub	Mainland	566725	2814761

Table 4. Amphibian detection in vegetation classification**.**

Species	Introduced	Disturbed	Mangrove	Mangrove Scrub	Prairie	Hammock
Acris gryllus			X	X		
Bufo marinus	X			X	X	X
Bufo quercicus						
Bufo terrestris				X		
Eleutherodactylus planirostris	X		X	X		X
Gastrophryne carolinensis			X			
Hyla cinerea			X	X		
Hyla squirella			X	X		
Osteopilus septentrioinalis	X	X	X	X		
Rana grylio			X	X		
Rana sphenocephala			X	X		

Table 5. Amphibian average proportion of area occupied estimate comparisons.

Species	PAO estimate	SE
Acris gryllus	35.0	0.2096
Bufo marinus	77.9	0.1499
Bufo quercicus	-	-
Bufo terrestris	-	-
Eleutherodactylus planirostris	54.4	0.1077
Gastrophryne carolinensis	-	-
Hyla cinerea	43.7	0.1519
Hyla squirella	-	-
Osteopilus septentrioinalis	48.6	0.1157
Rana grylio	-	-
Rana sphenocephala	48.6	0.0026

Table 6. Number of individuals captured and number of site visits during which at least one of each species was heard vocalizing out of 236 possible samples.

Species	Individual Captures	Visits with Vocalizations Detected	Total
Acris gryllus	0	6	6
Bufo marinus	0	31	31
Eleutherodactylus planirostris	38	26	64
Hyla cinerea	9	19	28
Hyla squirella	0	2	2
Osteopilus septentrionalis	49	21	70
Rana grylio	0	12	12
Rana sphenocephala	4	5	9
Total	100	122	222

Table 7. Months in 2003 during which individuals were detected by visual encounter survey methods and vocalization.

[VES. Visual Encounter Survey]

Survey Method	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acris gryllus												
VES												
Vocalization			X		X	X	X	X				
Bufo marinus												
VES												
Vocalization		X	X	X	X	X	X	X		X		X
Eleutherodactylus planirostris												
VES		X	X		X	X		X	X	X	X	
Vocalization					X	X	X	X	X			
Hyla cinerea												
VES					X	X	X	X				
Vocalization			X		X	X	X	X	X			
Hyla squirella												
VES												
Vocalization							X	X				
Osteopilus septentrionalis												
VES	X	X	X	X	X	X		X	X	X	X	
Vocalization		X		X	X	X	X	X	X	X		
Rana grylio												
VES												
Vocalization			X	X	X	X	X	X				
Rana sphenocephala												
VES						X		X				
Vocalization	X	X										

Table 8. Results of proportion of area occupied analysis for *Acris gryllus*.

[ψ (Psi) = The estimate of the proportion of sites occupied, SE, standard error of the estimate, k, number of parameters, ΔAICc , the difference from the lowest value of the Akaike's Information Criterion for small sample sizes]

Model	ψ	SE	-2log Likelihood	K	ΔAICc	Model Weight
Psi(island); p(.)	0.3498	0.2096	49.3498	3	0.0000	0.2426
Psi(.); p(.)	0.2639	0.1545	52.4231	2	0.6990	0.1710
Psi(.); p(water)	0.6502	0.5717	50.8756	3	1.5258	0.1131
Psi(island); p(water)	0.6502	0.5717	50.8756	3	1.5258	0.1131
Psi(island); p(temp)	0.3483	0.2085	49.2302	4	2.4031	0.0729
Psi(island); p(humid)	0.3468	0.2093	49.2633	4	2.4362	0.0717
Psi(.); p(temp)	0.2630	0.1543	52.3225	3	2.9727	0.0549
Psi(.); p(humid)	0.2596	0.1521	52.3484	3	2.9986	0.0542
Psi(.); p(temp, water)	0.6516	0.5756	50.8648	4	4.0377	0.0322
Psi(island); p(temp, water)	0.4645	0.3624	48.8539	5	4.7123	0.0230
Psi(island); p(temp, humid)	0.3451	0.2081	49.1687	5	5.0271	0.0196
Psi(.); p(temp, humid)	0.2588	0.1522	52.2664	4	5.4393	0.0160
Psi(.); p(temp, humid, water)	0.6711	0.5995	50.6239	5	6.4823	0.0095
Psi(island); p(temp, humid, water)	0.4995	0.4077	48.6233	6	7.3462	0.0062

Table 9. Contribution of four different variables to the occupancy model selection of six amphibian species. The values are the sum of Akaike weights of all models containing the variables.

Variable	*Acris gryllus*	*Bufo marinus*	*Eleutherodactylus planirostris*	*Hyla cinerea*	*Osteopilus septentrionalis*	*Rana sphenocephala*
Island	0.549	0.182	0.694	0.999	0.313	0.998
Air Temperature	0.234	0.407	0.997	0.639	0.384	0.991
Relative Humidity	0.177	0.496	0.489	0.215	0.455	0.206
Presence of Water	0.297	0.246	0.208	0.306	0.211	0.213

Table 10. Results of proportion of area occupied analysis for *Bufo marinus*.

[ψ = The estimate of the proportion of sites occupied, SE, standard error of the estimate, k, number of parameters, ΔAICc, the difference from the lowest value of the Akaike's Information Criterion for small sample sizes]

Model	ψ	SE	-2log Likelihood	K	ΔAICc	Model Weight
Psi(.); p(humid)	0.7527	0.1423	176.9638	3	0.0000	0.2930
Psi(.); p(.)	0.7748	0.1453	180.5923	2	1.2542	0.1565
Psi(.); p(temp, humid)	0.7553	0.1441	176.2032	4	1.7621	0.1214
Psi(.); p(temp)	0.7783	0.1481	178.9633	3	1.9995	0.1078
Psi(island); p(water)	0.8603	0.0807	179.5232	3	2.5594	0.0815
Psi(.); p(water)	0.7637	0.1415	180.0704	3	3.1066	0.0620
Psi(.); p(temp, water)	0.7637	0.1432	178.2828	4	3.8417	0.0429
Psi(island); p(temp)	0.8692	0.2342	178.5011	4	4.0600	0.0385
Psi(island); p(temp, humid)	0.8280	0.2153	175.9078	5	4.1522	0.0368
Psi(.); p(temp, humid, water)	0.7531	0.1421	176.0409	5	4.2853	0.0344
Psi(island); p(temp, water)	0.8585	0.0817	177.6792	5	5.9236	0.0152
Psi(island); p(temp, humid, water)	0.8411	0.2181	175.6452	6	6.7541	0.0100
Psi(island); p(.)	1.0000	0.0000	183.0214	3	99.0000	0.0000
Psi(island); p(humid)	1.0000	0.0000	180.1045	4	99.0000	0.0000

Table 11. Snout-to-vent length of amphibian species captured in Biscayne National Park.

[SD, Standard deviation]

Species	Number of Individuals	Mean Snout-Vent Length (+/- SD)	Range of Snout-Vent Length (mm)
Eleutherodactylus planirostris	6	19.33 (+/- 4.32)	11-23
Hyla cinerea	6	40.17 (+/- 5.85)	30-47
Osteopilus septentrionalis	20	57.45 (+/- 15.88)	34-95
Rana sphenocephala	1	80 (+/- 0)	80-80

Table 12. Results of proportion of area occupied analysis for *Eleutherodactylus planirostris*.

[ψ = The estimate of the proportion of sites occupied, SE, standard error of the estimate, k, number of parameters, ΔAICc, the difference from the lowest value of the Akaike's Information Criterion for small sample sizes]

Model	ψ	SE	-2log Likelihood	K	ΔAICc	Model Weight
Psi(island); p(temp)	0.5300	0.1007	174.8847	4	0.0000	0.2829
Psi(island); p(temp, humid)	0.5259	0.1006	172.2965	5	0.0973	0.2695
Psi(.); p(temp, humid)	0.5775	0.1151	176.5961	4	1.7114	0.1202
Psi(.); p(temp)	0.5812	0.1149	179.1717	3	1.7643	0.1171
Psi(island); p(temp, water)	0.5300	0.1009	174.8847	5	2.6855	0.0739
Psi(island); p(temp, humid, water)	0.5266	0.1011	172.2755	6	2.9408	0.0650
Psi(.); p(temp, water)	0.5837	0.1156	179.1141	4	4.2294	0.0341
Psi(.); p(temp, humid, water)	0.5811	0.1158	176.4549	5	4.2557	0.0337
Psi(island); p(water)	0.5399	0.1001	188.3529	3	10.9455	0.0012
Psi(island); p(.)	0.5405	0.1003	188.3717	3	10.9643	0.0012
Psi(island); p(humid)	0.5392	0.0999	187.5093	4	12.6246	0.0005
Psi(.); p(.)	0.5967	0.1180	193.1851	2	13.4033	0.0003
Psi(.); p(humid)	0.5939	0.1175	192.3706	3	14.9632	0.0002
Psi(.); p(water)	0.5979	0.1185	193.1708	3	15.7634	0.0001

Table 13. Results of proportion of area occupied analysis for *Hyla cinerea*.

[ψ = The estimate of the proportion of sites occupied, SE, standard error of the estimate, k, number of parameters, ΔAICc, the difference from the lowest value of the Akaike's Information Criterion for small sample sizes]

Model	ψ	SE	-2log Likelihood	K	ΔAICc	Model Weight
Psi(island); p(temp)	0.4409	0.1460	85.6807	4	0.0000	0.3665
Psi(island); p(water)	0.4399	0.1618	89.8806	3	1.6772	0.1585
Psi(island); p(.)	0.4480	0.1599	89.9193	3	1.7159	0.1554
Psi(island); p(temp, humid)	0.4398	0.1493	85.1491	5	2.1539	0.1249
Psi(island); p(temp, water)	0.4199	0.1438	85.5037	5	2.5085	0.1046
Psi(island); p(humid)	0.4366	0.1584	89.7859	4	4.1052	0.0471
Psi(island); p(temp, humid, water)	0.3827	0.1425	84.4379	6	4.3072	0.0425
Psi(.); p(temp)	0.2702	0.0916	103.5944	3	15.3910	0.0002
Psi(.); p(.)	0.2732	0.0928	107.1238	2	16.5460	0.0001
Psi(.); p(temp, humid)	0.2693	0.0915	102.7819	4	17.1012	0.0001
Psi(.); p(temp, water)	0.2623	0.0895	103.1157	4	17.4350	0.0001
Psi(.); p(temp, humid, water)	0.2482	0.0848	100.7582	5	17.7630	0.0001
Psi(.); p(humid)	0.2726	0.0924	106.6235	3	18.4201	0.0000
Psi(.); p(water)	0.2680	0.0917	106.9251	3	18.7217	0.0000

Table 14. Results of proportion of area occupied analysis for *Osteopilus septentrionalis*.

[ψ = The estimate of the proportion of sites occupied, SE, standard error of the estimate, k, number of parameters, ΔAICc, the difference from the lowest value of the Akaike's Information Criterion for small sample sizes]

Model	ψ	SE	-2log Likelihood	K	ΔAICc	Model Weight
Psi(.); p(humid)	0.4699	0.1095	193.0980	3	0.0000	0.2056
Psi(.); p(.)	0.4867	0.1125	196.0967	2	0.6244	0.1504
Psi(.); p(temp)	0.4822	0.1117	194.3231	3	1.2251	0.1114
Psi(.); p(temp, humid)	0.4685	0.1090	191.9424	4	1.3671	0.1038
Psi(island); p(humid)	0.4895	0.1184	192.6266	4	2.0513	0.0737
Psi(island); p(water)	0.5178	0.1267	195.1945	3	2.0965	0.0721
Psi(island); p(.)	0.5158	0.1261	195.4577	3	2.3597	0.0632
Psi(.); p(water)	0.4862	0.1123	195.8952	3	2.7972	0.0508
Psi(island); p(temp)	0.5123	0.1246	193.6117	4	3.0364	0.0450
Psi(.); p(temp, water)	0.4812	0.1113	193.9649	4	3.3896	0.0378
Psi(island); p(temp, humid)	0.4898	0.1178	191.3946	5	3.5048	0.0356
Psi(.); p(temp, humid, water)	0.4688	0.1091	191.9316	5	4.0418	0.0272
Psi(island); p(temp, water)	0.5145	0.1250	193.1624	5	5.2726	0.0147
Psi(island); p(temp, humid, water)	0.4916	0.1188	191.3585	6	6.3332	0.0087

Table 15. Results of proportion of area occupied analysis for *Rana sphenocephala*.

[ψ = The estimate of the proportion of sites occupied, SE, standard error of the estimate, k, number of parameters, ΔAICc, the difference from the lowest value of the Akaike's Information Criterion for small sample sizes]

Model	ψ	SE	-2log Likelihood	K	ΔAICc	Model Weight
Psi(island); p(temp)	0.4865	0.0000	34.0035	4	0.0000	0.6174
Psi(island); p(temp, water)	0.4865	0.0000	33.9442	5	2.6262	0.1661
Psi(island); p(temp, humid)	0.4865	0.0000	33.9631	5	2.6451	0.1645
Psi(island); p(temp, humid, water)	0.4865	0.0000	33.9209	6	5.4674	0.0401
Psi(island); p(water)	0.4230	0.1964	45.7645	3	9.2383	0.0061
Psi(island); p(.)	0.4865	0.0000	47.4744	3	10.9482	0.0026
Psi(.); p(temp)	0.3249	0.1573	48.6121	3	12.0859	0.0015
Psi(island); p(humid)	0.4865	0.0000	47.4438	4	13.4403	0.0007
Psi(.); p(temp, humid)	0.3218	0.1559	48.5575	4	14.5540	0.0004
Psi(.); p(temp, water)	0.3185	0.1675	48.6048	4	14.6013	0.0004
Psi(.); p(temp, humid, water)	0.3210	0.1700	48.5574	5	17.2394	0.0001
Psi(.); p(.)	0.3267	0.1757	60.1540	2	21.2534	0.0000
Psi(.); p(water)	0.2429	0.1113	58.6454	3	22.1192	0.0000
Psi(.); p(humid)	0.3298	0.1830	60.1486	3	23.6224	0.0000

Table 16. Reptile species observed during amphibian inventory in Biscayne National Park during 2002-2003 and method of detection.

Family	Genus	Species	Common Name	VES	Opportunistic
		Order Crocodylia			
Alligatoridae	*Alligator*	*mississipiensis*	American alligator		X
Crocodylidae	*Crocodylus*	*accutus*	American crocodile	X	
		Order Squamata, suborder sauria			
Gekkonidae	*Hemidactylus*	*mabouia*	Amerafrican house gecko	X	X
Gekkonidae	*Hemidactylus*	*garnotii*	Indo-Pacific gecko	X	X
Gekkonidae	*Sphaerodactylus*	*notatus*	Florida reef gecko	X	
Polycrotidae	*Anolis*	*sagrei*	Brown anole	X	X
Polycrotidae	*Anolis*	*carolinensis*	Green anole	X	X
Scincidae	*Eumeces*	*inexpectatus*	Southeastern five-lined skink		X
		Order Squamata, suborder serpentes			
Colubridae	*Diadophis*	*punctatus*	Southern ring-neck snake	X	X
Colubridae	*Elaphe*	*obsoleta*	Yellow ratsnake		X
Colubridae	*Elaphe*	*guttata*	Cornsnake		X
Colubridae	*Nerodia*	*fasciata*	Florida watersnake	X	X
Colubridae	*Nerodia*	*clarkii*	Mangrove saltmarsh snake		X
Typhlopidae	*Ramphotyphlops*	*raminus*	Brahminy blindsnake		X

Appendix I.

Acris gryllus		Best model: Psi (island), p (.)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	0.4159	1.6137	0.6025	0.3865
Psi	Island	-2.5025	1.7532	0.0757	0.1226
p	intercept	-2.3085	0.6702	0.0904	0.0551

Anolis sagrei		Best model: Psi (island), p (humid, temp, water)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	0.6128	0.7766	0.6486	0.177
Psi	Island	24.0875	-105666	1	0
p	intercept	-1.2533	0.4164	0.2221	0.072
p	Humid	10.9642	3.6694	1	0.0001
p	Temp	-0.183	0.051	0.4544	0.0127
p	Water	-0.7167	0.3821	0.3281	0.0842

Bufo marinus		Best model: Psi (.), p (humid)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	1.1129	0.7642	0.7527	0.1423
p	intercept	-2.5413	0.5685	0.073	0.0385
p	Humid	9.0023	4.8832	0.9999	0.0006

Hemidactylus mabouia		Best model: Psi (.), p (temp, humid)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	0.8677	1.0358	0.7043	0.2157
p	intercept	-3.3859	0.7947	0.0327	0.0252
p	Humid	10.1017	6.6417	1	0.0003
p	Temp	-0.1485	0.1095	0.4629	0.0272

Osteopilus septentrionalis		Best model: Psi (.), p (humid)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	-0.1204	0.4396	0.4699	0.1095
p	intercept	-1.4576	0.4933	0.1888	0.0756
p	Humid	7.8882	4.6394	0.9996	0.0017

Rana grylio		Best model: Psi (island), p (humid, temp, water)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	-0.7092	0.6263	0.3298	0.1384
Psi	Island	-59.2799	-1.3E+07	0	0
p	intercept	6.7306	3.574	0.9988	0.0043
p	Humid	-50.919	-27.9418	0	0
p	Temp	-0.5067	0.207	0.376	0.0486
p	Water	-6.1256	2.6192	0.0022	0.0057

Rana sphenocephala		Best model: Psi (island), p (temp)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	33.5623	0	1	0
Psi	Island	-61.6169	0	0	0
p	intercept	-3.0365	2.1547	0.0458	0.0942
p	Temp	0.3612	12.0686	0.5893	2.9208

Sphaerodactylus notatus		Best model: Psi (.), p (humid, temp, water)			
		Beta	SE	95percent CI lower	95percent CI upper
Psi	Intercept	-0.7396	0.5411	0.3231	0.1183
p	intercept	-3.4042	1.1788	0.0322	0.0367
p	Humid	14.6034	9.0538	1	0
p	Temp	-0.3668	0.2155	0.4093	0.0521
p	Water	-19.8725	-10488.9	0	0

Appendix II. Biscayne National Park website list of reptiles present.

Genus	Species	Sub Species	Common Name
Alligator	*mississipiensis*		American Alligator
Crocodylus	*accutus*		American Crocodile
Elaphe	*guttata*	guttata	Cornsnake
Elaphe	*obsoleta*	rossalleni	Everglades Rat Snake
Tantilla	*coronata*	wagneri	Florida Crowned Snake
Sistrurus	*miliarius*	barbouri	Dusky Pigmy Rattlesnake
Crotalus	*adamanteus*		Eastern Diamond-backed Rattlesnake
Drymarchon	*corais*	couperi	Eastern Indigo Snake
Coluber	*constrictor*	paludicola	Everglades Racer
Terrapene	*carolina*	bauri	Florida Box Turtle
Eumeces	*egregius*	egregius	Florida Keys Mole Skink
Sphaerodactylus	*notatus*	notatus	Florida Reef Gecko
Nerodia	*fasciata*	pictiventris	Florida Watersnake
Anolis	*carolinensis*		Green Anole
Micrurus	*fulvius*	fulvius	Harlequin Coralsnake
Dermochleys	*coriacea*		Leatherback Seaturtle
Scincella	*lateralis*		Little Brown Skink
Hemidactylus	*turcicus*		Mediterranean House Gecko
Tantilla	*oolitica*		Rim Rock Crowned Snake
Opheodrys	*aestivus*		Rough Greensnake
Eumeces	*inexpectatus*		Southeastern Five-lined Skink
Seminatrix	*pygaea*	cyclas	Southern Florida Swampsnake
Diadophis	*punctatus*	punctatus	Southern Ring-neck Snake
Kinosternon	*baurii*		Striped Mud Turtle
Elaphe	*obsoleta*	quadrivittata	Yellow Ratsnake